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SPACE PHYSICS AND SPACECRAFT

by G. A. Skuridin

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SPACE PHYSICS AND SPACECRAFT

G. A. Skuridin[1]

ABSTRACT. In the first half of this book the author gives a historical review of the study of solar-terrestrial relationships. Included among the topics in this section are the Chapman-Parker theory, the origin of the solar wind, the model of the interplanetary medium, along with the Earth's magnetic field and magnetic storms, the Chapman-Ferraro theory of magnetic storms, the structure of the geomagnetic field, and a model of the Earth's magnetosphere. In addition he discusses the Earth's radiation belt, the measurement of the low-energy plasma and the "knee effect", the magnetosphere's boundary and the dynamics of charged particles, the ring current of magnetic storms, polar aurorae, and the interaction of geophysical phenomena and their origin. In the second part of this pamphlet the author gives a historical review of USA and USSR manned and unmanned spacecraft. Among the topics discussed in detail are the USSR's "Kosmos", "Elektron", "Proton", and "Zond" unmanned spacecraft series; the author also covers the US space program in a concise but thorough manner.

"Happy are those who develop science during years when it is incomplete but when a decisive catechism has matured in it." /3*

Ampère

"Time eliminates prejudices and confirms the law of nature."

Cicero

SOLAR-TERRESTRIAL RELATIONS

Artificial Earth satellites and space rockets first permitted accomplishing a series of fundamental experiments in near-Earth outer space. The results of these experiments led to a fundamental revision of our ideas about the processes which occur in the Earth's immediate surroundings.

At present the most complicated geophysical phenomena, such as polar aurorae, magnetic storms, radiation belts, and ionospheric disturbances, appear

[1]Doctor of Physical-Mathematical Sciences.
*Numbers in the margin indicate pagination in the foreign text.

to us as different aspects of a single problem. One can assume that these phenomena are caused mainly by the nature of the interaction of solar corpuscular streams with the Earth's magnetic field. The study of this interaction, which is the task of a new area of astrophysics, is the physics of the magnetosphere. The scales of the phenomena which we observe in polar aurorae, magnetic storms, ionospheric disturbances, the radiation belts, and also the magnetic "trail" of the Earth capture the imagination. The grandeur of space phenomena increases in proportion to how well our attempts to understand their causality and origin cope with the never-ending new difficulties.

We will dwell briefly on the development of some ideas which at present play a fundamental role in our understanding of magnetospheric physics.

The history of these ideas is instructive in the respect that, although they were pointed out in the last century, they did not exert any kind of effect on the subsequent understanding of many experimental facts which were discovered and required more than half a century to be generated anew. Thus, in 1892-1900 Fitzgerald and Lodge proposed that magnetic storms are produced by a stream or cloud of charged particles, that polar aurorae are caused by a stream of cathode rays, and that comet tails cannot be explained only by the action of solar pressure but evidently the solar radiation, emitted from the region of sunspots with an average velocity of around 300 km/sec, plays a significant role in their formation.

Finally, Fitzgerald and Lodge assumed, based on the fact that polar aurorae and magnetic storms exist, that the Earth, like comets, should possess a small tail directed away from the Sun.

Fitzgerald and Lodge's ideas were subjected to criticism by Lord Kelvin, and therefore they were partially forgotten. In addition Fitzgerald and Lodge assumed that the corpuscular radiation consists of cathode rays, i.e., electrons which are ejected from sunspots by intense chemical reactions occurring on the Sun.

At the same time Birkeland carried out his famous experiments with a magnetized sphere in a vacuum. As a result he concluded that polar aurorae are caused by "corpuscular rays", understanding them to be a stream of charged particles coming from the Sun. Furthermore, Birkeland expressed a series of brilliant ideas on the basis of the laboratory experiments and the expedition work performed under exceptionally difficult conditions. Thus he assumed:

1) A ring current of quasi-trapped particles occurs in the equatorial plane;

2) A partial ring current exists along with a system of currents which is locked in the ionosphere;

3) Limited active regions occur on the Sun which constantly emit radiation which causes magnetic storms with a periodicity of 27 days, which is equal to the Sun's period of rotation around its axis;

4) Since weak magnetic storms occur constantly, the effect of solar rays occurs at any time (i.e., he assumed in fact the existence of a constant "solar wind");

5) Comet tails are formed as the result of "sputtering of material from comet nuclei (carbon) by solar corpuscular rays";

6) The winter magnetic field gives rise to the appearance of a near-Earth band from which soft solar particles are swept out, i.e., he foresaw the formation of the ionosphere.

Birkeland inspired K. Störmer to write a book about polar aurorae and cosmic rays.

K. Störmer obtained a series of remarkable results which explained the nature of a motion of particles in a magnetic field. To this should be added the entire series of observations which it was possible to explain in /5
particular by a constant solar radiation:

1) The appearance each night of certain shapes of polar aurorae at high latitudes;

2) Magnetic activity is always observed at polar latitudes;

3) The lowering in the intensity of cosmic rays at the Earth during the period of high solar activity (the Forbush effect).

During the 1950's papers of the German scientist L. F. Biermann appeared which were devoted to the study of comet tails.

It is known that a comet's head is almost always directed towards the Sun but its gaseous tail is directed away from the Sun (an exception is the Arend-Roland Comet with two tails, one of which is directed away from the Sun, and the other, in the form of a giant needle, is directed towards the Sun).

The nature of the tail (its curvature, its deviation from the radius vector, and so forth) depends on the acceleration which its particles receive. According to the mechanical theory, the force of radiation pressure is assumed to be the force which accelerates the particles of a comet tail. However, the mechanical theory does not explain a series of specific phenomena in the tails of Type I comets.

L. Biermann showed that many characteristic peculiarities of Type I comet tails can be satisfactorily explained as the result of the interactions of a comet tail's plasma with a solar corpuscular stream.

L. Biermann's theory was subjected to criticism for a number of reasons. However, its basic idea on the effect of corpuscular streams on comet tails is correct. Furthermore, it was shown that the magnetic field carried by the solar stream plays the basic role in the interactions of solar corpuscular streams with a cometary atmosphere.

It follows from a comparison of all of the facts discussed that corpuscular radiation is constantly emitted by the Sun and influences the atmosphere and the magnetic field of the Earth. This radiation is emitted in all directions, and the velocity of propagation increases immediately after an outburst on the Sun.

Furthermore, we will see how these ideas were transformed into the contemporary concept of solar-terrestrial physics and how scientists gradually arrived at an understanding of the unity of solar and geophysical processes. This became possible as a result of the global study of phenomena with the help of space instruments and the comparison of the data obtained with ground-based observations.

However, let us turn to the middle of the 1950's. At this time a series of disturbing problems arose before scientists: what cause produces the continuous outflow of corpuscular streams from the Sun, what kind of sources are there for the outflow, what are the density and velocity of propagation of the streams, and what is the nature of their interaction with the interplanetary medium and the magnetic fields of the planets of the solar system? /6

The very important research of the Soviet astrophysicists A. B. Severnyy, E. P. Mustel', V. A. Krat, and S. B. Pikel'ner was devoted to the study of this complex of problems.

V. A. Krat and S. B. Pikel'ner's calculations showed that at the assumed kinetic temperature of the solar corona of about 1.5 million degrees an inevitable escape of a large number of coronal particles from the Sun occurs, the so-called thermal dissipation. However this turned out to be insufficient to explain the constant outflow from the solar corona. Solar corpuscular streams were identified with the coronal rays, and a dynamic model of the solar corona was discussed in the papers of S. K. Vsekhsvyatskiy, Ye. A. Ponomarev, G. M. Nikol'skiy and V. I. Cherednichenko during 1953-1957. Unfortunately, these authors did not draw an important conclusion from their theory on the expansion of the solar corona into outer space.

The Chapman-Parker Theory

At present the Chapman-Parker theory is the most developed theory on the corpuscular streams continuously ejected by the Sun. The research of Sydney Chapman, one of the greatest theoreticians of our time, showed that if the temperature of a solar corona is about 1 million degrees, then the ionized gas of the corona produces a large heat flux due to its high thermal conductivity and extends out to the Earth's orbit, having a temperature of about 200,000° K at this distance.

Based on the data on a corona's density, S. Chapman obtained a value of about 100-1,000 hydrogen atoms per cm^3 for the corona's density near the Earth which agrees with the data obtained earlier from measurements, for example, of the zodiacal light. S. Chapman figuratively stated that we live "in an extension of the solar corona". The insufficiency of this theory lies in the fact that S. Chapman discussed the solar corona in hydrostatic equilibrium. In addition, the interplanetary magnetic field was not combined with the interplanetary plasma in Chapman's theory.

Developing further the ideas of S. Chapman, the American astrophysicist E. Parker showed that the solar corona cannot be in hydrostatic equilibrium. E. Parker examined the problem of hydrosynamic expansion of the solar corona /7 and arrived at the unusual result that the rate of expansion to "infinity" has, as a lower limit, the value

$$v\ (\infty) > \left(\frac{10}{9}\ \frac{3kT}{m}\right)^{1/2},\ \text{i.e.,}$$

the solar corona is expanding, attaining velocities of several hundreds of kilometers per second at a distance of about 10 million kilometers.

If, according to Parker, one assumes that the corona's density at its base is $N = 3 \cdot 10^7\ cm^{-3}$, then we obtain a value of $2 \cdot 10^2\ cm^{-3}$ at the Earth's orbit.

Hence, Parker drew the important astrophysical conclusion that the hydrodynamically expanding solar corona represents the corpuscular radiation of the Sun. E. Parker called this continuous supersonic flux emitted by the Sun, the "solar wind."

In 1959 the first Soviet automatic rockets were launched toward the Moon with instrumentation for the study of interplanetary space.

The experiments on the measurement of the interplanetary plasma were carried out under the direction of Doctor of Engineering Sciences K. I. Gringauz. The solar particle streams were first recorded in these experiments. The velocity of the recorded streams equalled $\sim$400 km/sec, and the particle concentration in the stream varied within the limits of 25 particles per cm^3.

The first American measurements of the solar plasma were carried out on the Explorer-10 high-apogee satellite (its maximum distance from the Earth was almost 200,000 km) by the experiment of Rossi, Bridge, and others in March 1961. The sizes of the solar streams and their velocities were measured in these experiments, and they turned out to be equal to 400-500 km/sec. The value of the stream amounted to 10^8-10^9 particles$\cdot$cm$^{-2}\cdot$sec^{-1}. However all the experiments were short-lived and of a fragmentary nature.

The almost continuous 4-month measurements of the solar plasma velocities by the American space vehicle, Mariner-2 finally established the constant existence of a solar wind in interplanetary space whose velocity at the Earth equalled 300-500 km/sec. Reduction of the results of these measurements permitted establishing an emperical formula which determines the dependence between the average (over days) velocity of the solar wind and the index of magnetic activity:

$$V = 8.44 \, \Sigma K_p + 330 \text{ km/sec.}$$

Here ΣK_p is the sum for days of the indices K_p corresponding to 3-hour intervals.

Thus the direct measurements by space instruments verified in general /8
the astrophysical ideas of E. Parker on the nature of the solar wind, which is a most important scientific achievement in the investigation of outer space. This discovery is important not only from the point of view of dynamical processes occurring on the Sun and the interplanetary medium, but it has a fundamental meaning for the understanding of many geophysical phenomena near the Earth, their interaction and the unity of their origin.

Evidently the solar wind is exactly that cosmic "disturber of tranquility" which is responsible in th- first place for many processes in near-Earth outer space.

Origin of the Solar Wind

The theory of the solar wind is based on a specific physical model with whose help it is possible to obtain an idea about the expanding solar corona. The solar wind as a stream of low-density ionized gas represents the outer part of the solar corona, which has a rather high kinetic temperature.

According to the fundamental idea of I. S. Shklovskiy (1944) only the low density of the material in the corona and the small associated losses of coronal plasma by radiation serve as the cause of the high kinetic temperature of the solar corona. Explanation of the nature of the "heating mechanism" is, along with the origin of the solar wind, a fundamental problem for the physics of the solar corona. What makes the corona so hot?

Physicists presently assume that a process of energy dissipation, i.e., transformation of the energy of the gas's ordered motion into the energy of disordered "thermal" motions, may serve as the "heating mechanism". Thus the liberation of Joule heat in a conducting ionized gas may serve as a typical example of energy dissipation.

What form of energy dissipation can one assume in the solar corona? Because of the special conditions in the corona, as in any other kind of plasma, complicated magnetohydrodynamical processes occur which result in the appearance of magnetohydrodynamical waves.

In addition to magnetohydrodynamical waves, the existence in the solar plasma of a different type of acoustical wave is possible, which evidently arise because of the powerful convective motions in the regions lying below the Sun's photosphere.

Schwarzschild and Biermann assumed that the dissipation of mechanical energy by acoustical magnetohydrodynamical waves may act as the source of heating of the solar corona. These waves transmit part of their energy to /9
the surrounding gas through which they pass. Because of the low density very little heat is necessary to raise the corona's temperature.

As E. Parker writes, this process recalls the activity of a boy who by rubbing two wooden sticks together produces sufficient heat to light a fire whose temperature reaches several hundreds of degrees, although the boy's own temperature amounts to only 37°C. The temperature of the surrounding gas increases from 5,000°K in the photosphere to $1.5 \cdot 10^{6}$°K at the base of the corona, where the dissipation of the main part of the energy occurs. This "heating mechanism" of the solar corona leads to its expanding and the outflow of coronal gas into interplanetary space. The outflow of plasma near the Sun proceeds comparatively slowly, $\sim$10-20 km/sec. The velocities increase in proportion to the distance from the Sun, reaching the velocity of sound and then supersonic velocities. This continuous acceleration of the plasma occurs because of the action of forces produced by the difference in pressures near the Sun and at great distances from it.

The energy dissipation increases above active regions of the solar surface, especially during powerful solar flares -- one of the striking phenomena of space explosions. One of the remarkable properties of the solar wind as a low-density highly ionized gas is the "freezing-in" of a magnetic field of solar origin into the plasma of the solar wind; this moving electrically conducting medium drags the magnetic field along behind it.

E. Parker advanced an idea in 1958 as to the effect of the solar magnetic field on the streams of the solar wind. We will consider, following E. Parker, the process of outflow of the solar plasma from some region on the Sun. We will assume that on the Sun's surface, at the level of its photosphere, magnetic fields have a strength of the order of ~1 oersted. The outflow of plasma from the region under consideration proceeds radially. Because of the Sun's rotation, the magnetic field's lines of force, which are "rigidly fastened" to the plasma and the Sun's surface, will be twisted. The vector of the magnetic field strength will be directed along the tangent at each point of the line of force. The angle α formed by the magnetic field strength vector and the vector of the solar plasma's radial velocity is determined from the relation

$$\tan \alpha = \frac{\omega R}{V},$$

where ω is the Sun's angular velocity; R is the radial distance to the point under discussion on the field's force line; and V is the plasma's velocity. The angle α amounts on the average to ~45° at a distance of ~1 a.u. (a.u. /10
is the astronomical unit) for a solar wind velocity of ~450 km/sec.

The shape of the force line, along which the magnetic fields are extended and which are carried along by the solar wind, depends on the ratio between the solar wind's kinetic energy density:

$$W_K = 1/2\ \rho v^2$$

and the magnetic energy density

$$W_M = \frac{H^2}{8\pi}$$

Upon fulfillment of the condition $W_K \gg W_M$, the equation for the force lines acquires the shape of the Archimedes spiral.

An important conclusion follows from this -- interplanetary fields are none other than the "frozen-in" magnetic fields of the solar atmosphere carried along by the solar wind. Because of the fact that the total magnetic flux should maintain a constant value at all distances from the Sun, it is possible to estimate the strength of the magnetic fields in the Earth's region. For an assumed value for the strength of the magnetic field on the Sun of $H_{Sun} \sim 1$ oersted and on the basis of the relationship $H = H_{Sun}\left(\frac{R_{Sun}}{R}\right)^2$, we obtain a value for the interplanetary field strength of several gamma ($1_\gamma = 10^{-5}$ oersted).

Measurements carried out by Soviet and American space instruments have shown that interplanetary space is filled with magnetic fields having a strength of several gammas, which has also confirmed the general idea of a solar wind. A large series of investigations based on measurements of the magnetic fields in interplanetary space was carried out by the American space instruments of the IMP series under the direction of Norman Ness.

During the measurements (November 27, 1963 to February 15, 1964) the Sun completed several rotations about its axis. This permitted detecting a noticeable peculiarity of the interplanetary magnetic fields, namely, their sectoral structure centered on the Sun, i.e., the fields possess opposite signs: towards the Sun and away from the Sun.

The measurements have shown that magnetic fields that exist at every point in space have a spiral structure; the shape of the spiral corresponds to an average velocity of the plasma's motion of ~450 km/sec. The position of the spiral's plane is very close to the ecliptic plane according to the measurements carried out.

E. Parker's model is a model of the quiet Sun. However it is known that storm processes often occur on the Sun, for example, eruptions of huge masses of solar gas. So-called active regions exist which move across the solar disk because of the Sun's very rotation. /11

All these circumstances are not taken into account in Parker's idealized model.

Gold proposed another model, which is based on a discussion of the Sun's active regions. During intense chromospheric outbursts from active regions of the Sun, an eruption of solar plasma occurs which, expanding, expels the magnetic field of the active region from the solar surface. The ends of the magnetic field's lines of force remain "fastened" to the Sun during the plasma's expansion. The magnetic field is stretched out into a loop, forming an unusual magnetic bottle. Inside the magnetic bottle charged particles trapped by the magnetic field move along loops -- the lines of force. The particles arriving at the outside are reflected by the bottle's magnetic field. The magnetic field inside the bottle is estimated by Gold to amount to 1-10 gammas based on the initial phase of the Forbush effect.

Model of the Interplanetary Medium

Analysis of magnetic measurements by the IMP satellite series shows that interplanetary magnetic fields are localized fields of separate regions of the Sun which are carried along by the solar wind. Thus the actual interplanetary magnetic field essentially synthesizes both Parker's and Gold's models: on the one hand, the field is twisted into Parker's Archimedean spiral; on the other hand, this is not the "general" dipole field of the Sun but the field of separate local regions on the Sun's surface which are carried along by the solar winds (Gold's model).

During 1958-1963 the most important measurements of the distribution of the magnetic field in interplanetary space (Ness, Dolginov) and the plasma density (Gringauz, Neugebauer, Snyder) were conducted. The values of the resulting quantities were averaged over time and space. However these values cannot be used as characteristics of the basic parameters of the interplanetary plasma, namely, the concentration (n) the velocity (v), the electron (T_e) and

and ion (T_i) temperatures, and the magnetic field strength (H). It was necessary to know the values of the parameters referred to one and the same time interval Knowledge of the set of plasma parameters permits selecting this or the other /12 physical model of the interplanetary plasma:

$$nkT_e \gg \frac{H^2}{8\pi} \text{ -- hot plasma,}$$

$$nkT_e \ll \frac{H^2}{8\pi} \text{ -- cold plasma.}$$

Here k is Boltzmann's constant.

It has been shown recently that both models are realized in the interplanetary plasma, and the flow of the plasma is always supersonic.

Data on direct measurements of the velocities of the solar plasma streams in the immediate vicinity of the Sun are lacking at present. In this connection the radar measurements of the Sun carried out in 1962 at a frequency of 38 MHz have important meaning. Analysis of the measurements showed that at an altitude of 350,000 km above the Sun's photosphere the solar coronal expansion occurred with a velocity of 16 km/sec. This value is very similar to the theoretical one for the given altitude at a coronal temperature of $T = 10^{6}$°K.

Discovery of the solar wind and study of the dynamic processes in interplanetary space have resulted in a complete revision of our ideas about the physics of near-Earth outer space. The swift accumulation of experimental data has set the pace for the development of space physics, its new concepts, ideas, and hypotheses. In the first place this has touched on our ideas as to the structure of the geomagnetic field at great distances and the nature of the solar wind's interaction with the Earth's magnetic field.

The Earth's Magnetic Field and Magnetic Storms

Towards the end of the 19th century the idea of the Earth's constant magnetic field (H_i) and variable magnetic field (H_e) was worked out. Study of magnetic storms served as the first impetus to rejection of the model of an unbounded geomagnetic field.

The field of a magnetic storm was assumed, according to Chapman, to represent a set of currents determining the characteristic peculiarities of the storm:

$$D = DCF + DR + DP,$$

where DCF is the current system producing the initial phase of the storm under the action of a solar corpuscular stream (CF stands for Corpuscular Flux); DR is a current ring responsible for the storm's main phase (R stands for Ring); /13 and DP is the ionospheric current system which is particularly intense in the polar region (P stands for Polar).

The onset of particularly strong magnetic storms is characterized by a sharp increase in the horizontal component, (H_{hor}), of the magnetic field strength. H (storms with a sudden onset). The instant of onset at various points on the Earth rarely differs by more than a minute. Later the storm's initial phase (sometimes very short) follows, and then the main phase with a duration of several hours. During the storm H_{hor} drops below the average undisturbed level whereupon the disturbance is significantly greater in absolute value than the disturbance during the sudden onset. After a minimum H_{hor} a return to the original level follows which takes up to several days. This is the recovery phase of the storm.

Storms with a gradual onset are also observed, which are associated with sunspots (more accurately, with the active so-called M-regions on the Sun). They reveal a tendency to a 27-day cycle (the Sun's period of rotation about its axis). The description of the disturbance during magnetic storms is averaged over a large number of storms. The nature of the disturbances is similar for all geomagnetic latitudes below 60°. At high latitudes the nature of occurrence of magnetic disturbances has a series of specific peculiarities, namely, polar storms. During a magnetic storm the polar aurorae, which are often observed at lower latitudes, are more intense than they usually are. Thus, during the storm of February 10-11, 1958, the polar aurorae were visible even in the tropics. During a magnetically quiet period the maximum frequency of appearance of polar aurorae is noted at geomagnetic latitudes of around 67°. The belt of these latitudes is called the polar auroral zone. The frequency of appearance of aurorae near the poles is significantly lower, and it decreases almost to zero at latitudes below 50°.

The Chapman-Ferraro Theory of Magnetic Storms

S. Chapman and V. Ferraro made an attempt in 1930 to explain geomagnetic disturbances on the basis of their theory of the initial phase of a magnetic storm. They assumed that magnetic storms arise as a result of the effect on the geomagnetic field of a stream of ionized gas consisting of positively and negatively charged particles ejected by the Sun. At a stream velocity of around 1,000 km/sec such a stream reaches the Earth 30 hours after the flare on the Sun. If the gas's conductivity is very great, then the magnetic field cannot penetrate through the stream's boundary. Electrical currents which arise at this boundary push the Earth's magnetic field out of /14
the region occupied by the stream. The magnetic field's lines of force will be deformed and compressed to a dipole from the side exposed to the Sun. The magnetic pressure opposes the stream's motion. Therefore if the stream's boundary was initially a plane parallel to the dipole's axis, then upon approaching the dipole, it is twisted and stopped there where the stream's pressure, P_0, becomes equal to the magnetic pressure, $H^2/8\pi$. Further from the dipole its field has little effect on the stream's motion. Therefore the stream flows around the dipole, forming a cavity within which the Earth's magnetic field is included (the Chapman-Ferraro cavity.)

To explain the decrease in the field strength during the storm's main phase, S. Chapman and V. Ferraro assumed the possibility of the capture of charged particles by the geomagnetic field and the formation from them of a ring current directed westward at a distance of about 10 R_E, where R_E is the Earth's radius. The Chapman-Ferraro theory appeared to be essentially the first theory proving the possibility of deformation of the geomagnetic field under the influence of solar streams and the development of a series of geophysical phenomena thereby.

Structure of the Geomagnetic Field

Experiments on Soviet and American spacecraft have permitted deriving the configurations of the actual stationary geomagnetic field. The geomagnetic field is included within a certain region called the Earth's magnetosphere (the term belongs to Gold), whose boundary during a magnetically quiet time is located at a distance of about 10 Earth radii on the daytime side and on the nighttime side at a distance of more than 30 Earth radii.

The magnetosphere's boundary region is several Earth radii in extent and is characterized by a sharp drop off of the field strength, fluctuations. and a gradual transition to the interplanetary field. The existence of the front of a standing shock wave, which separates the magnetosphere from the undisturbed solar wind, is detected from the daytime side. There exists within the magnetosphere on the daytime and nighttime sides a region of charged particles captured by the solar wind and called the Earth's radiation belt.

The first direct measurements of the geomagnetic field in near-Earth outer space were carried out in 1958-1959 by the "Luna-1" and "Luna-2" space- /15 craft and also by the American Pioneer-1 spacecraft. The measurements showed that starting from some distance from the Earth's center ($\sim$3-5 R_E) the magnetic field differs noticeably from a dipole's field (the Dolginov-Pushkov effect). It might have been suggested that starting at a distance, $R \sim$ 5-6 R_E) on the side exposed to the Sun, the drop in the field strength with increasing R is sharply slowed down.

In 1960 magnetic measurements of the outer regions of the geomagnetic field were carried out and a series of discrete measurements at distances of 5-30 R_E was completed with the help of the Pioneer-5 spacecraft launched into a near-solar orbit. The magnetic measurements showed that the geomagnetic field corresponds in its undisturbed state to a dipole field to distances of approximately 5-9 R_E.

The first results, which proved the existence of the magnetosphere's boundary, were obtained in 1961 with the help of the measurements of the magnetic field and plasma particles by the Explorer-10 and Explorer-12 satellites. The measurements showed the boundaries of a regular geomagnetic field, past which the solar wind flows. Explorer 12 discovered an effect of constraining a quasi-thermalized plasma, which was interpreted as the front of a collisionless shock wave, and also the effect of the reversal of the magnetic field strength vector at the magnetosphere's boundary. In addition it was shown that near the interior side of the magnetosphere's boundary the geomagnetic field strength is larger by a factor 2 than the dipole's field strength.

Thus on the basis of the results obtained, one can assume that three different regions, distinguished by their own properties, are characteristic of the actual geomagnetic field:

1) The interior region of the magnetosphere with an undisturbed dipole field;

2) An exterior region in which the actual field strength is higher than the strength of a dipole field; and

3) A boundary region whose field makes the transition into the interplanetary field.

This last region evidently has a complicated structure. In the region nearest the magnetosphere's boundary, a sharp drop-off in the geomagnetic field strength occurs. Strong field fluctuations are characteristic of this region. Further out in the 12-15 R_E region the field is less disturbed and, finally, in the region beyond 15-16 R_E the geomagnetic field trails off into the undisturbed interplanetary magnetic field.

The first magnetic measurements on the antisolar side of the Earth were carried out by the Soviet spacecraft, "Luna-2". Such investigations were carried out in 1961 by the American satellite, Explorer-10.

Fundamental investigations of the geomagnetic field were carried out /16
by N. Ness and his coworkers during 1963-1968 with the satellites of the IMP and Pioneer series. The first results of magnetic measurements on the Earth's nighttime side made with the help of the IMP-1 satellite showed that the geomagnetic field in the antisolar direction extends out to the Moon's orbit, forming the greatly extended and exposed "magnetic tail" of the Earth. The diameter of the magnetosphere's tail is approximately equal to 40 R_E. There

is a neutral layer inside the tail in the equatorial plane separating the magnetic lines of force, which have an antisolar direction in the southern hemisphere and a solar direction in the northern hemisphere. The magnetic field strength in the neutral layer is close to zero. Further measurements by the Pioneer satellites show that the Earth's magnetic tail evidently extends out to a distance of ~1,000 R_E.

Instruments contained on the IMP-1 satellite permitted establishing the conjectured existence of a collisionless shock wave front.

Model of the Earth's Magnetosphere

Contemporary ideas as to a model of the magnetosphere are based on the nature of the interaction of the Earth's magnetic field with a steady supersonic stream of ionized gas, namely, the solar wind.

It is possible to present a qualitative picture of the flow around the geomagnetic field by the solar wind in the following manner. Upon the flow around the magnetosphere by a supersonic solar stream a standing shock wave is formed in front of the magnetosphere. Passing through its front, the stream becomes subsonic, and the density and pressure in it are increased. The properties of shock waves in a tenuous magnetized plasma differ significantly from the properties of the usual hydrodynamic waves. For example, in a tenuous plasma the existence of shock waves with a front whose thickness is less than the mean free path of the particles is possible. An effect on a charged particle "leading" a wave front can occur by means of the magnetic field. The plasma conditions on both sides of the shock wave front are connected by the appropriate conservation laws. The picture of the streamline flow is complicated in the region between the shock wave front and the magnetosphere's boundary. Near the magnetosphere's boundary, a boundary layer is formed in which electrical currents flow. Outside the magnetosphere they shield the solar plasma from the Earth's magnetic field and increase the magnetic field strength inside the magnetosphere. The steady stream of solar plasma exerts a pressure on the magnetic fields, and the position of the magnetosphere's boundary on the solar side is determined from the condition of equality of the plasma's pressure with the magnetic field pressure: /17

$$\frac{H_t^2}{8\pi} = 2\ mnv^2 \cos^2\psi,$$

where H_t is a component of the Earth's magnetic field at the magnetosphere's boundary, tangent to the line of force (the tangential component); n is the number of protons in 1 cm^3; m is the proton's mass; v is the solar wind velocity; and ψ is the angle between the solar wind direction and the normal to the magnetosphere's boundary.

It is simplest to determine the distance to the magnetosphere's boundary in the direction of the Earth-Sun line. In this case $\cos^2 \psi = 1$ and we obtain:

$$r_0 = R_E \left(\frac{H_0^2}{16\ \pi mnv^2} \right)^{1/6}.$$

In the case of a solar wind velocity of $\sim$500 km/sec and a particle density $\sim$2.5 particles per cm^3, the magnetosphere's boundary is located at a distance of 10 R_E. Upon intensification of the solar wind (during an increase in its velocity or density) the distance to the magnetosphere's boundary is decreased, and in the case of a weakening of the solar wind, it is increased.

The first exact solution of the two-dimensional problem of the hydrodynamic flow around the Earth's magnetosphere by a free-molecular supersonic stream with a Mach number $M > 3$ was given by V. N. Zhigulev and Ye. A. Romishevskiy in 1959. Many peculiarities of the magnetosphere's structure were remarked on in their paper: its boundary on the solar side, the effect of an inclination of the dipole's axis towards the position of the so-called neutral points, the openness of the lines of force in the antisolar direction, and the antisymmetry in the Sun-Earth direction.

The solution of the three-dimensional problem has been obtained for the present by approximate methods for a series of simplifying assumptions. On the side exposed to the Sun at latitudes up to 70° the magnetosphere's boundary differs little from a spherical one. The magnetic field strength vector has only a tangential component on the boundary, with the exception of the neutral points, where the magnetic field strength is equal to zero.

The topology of the closed lines of force has an antisymmetrical nature along the Sun-Earth line on the solar and antisolar sides. The lines of force emerging from the region of high latitudes are carried away in a direction opposite to the solar stream''s motion forming a greatly elongated magnetic /18 tail, which can be closed (closed model) or open (open model) depending on the assumption made in the problem's solution. A description of the shape and structure of the geomagnetic tail is the most complicated problem. It is necessary to introduce another series of assumptions, for example, an additional field of a certain uniform current flowing on the nighttime side in the equatorial plane, starting from a geocentric distance of ~ 8-10 Earth radii.

Study of the geomagnetic field is closely associated with study of the distribution of charged particles within the magnetosphere, on its boundary, in the boundary region, and in the magnetic loop.

The Earth's Radiation Belt

The discovery of a zone of trapped radiation -- the Earth's radiation belt -- was one of the remarkable and, one could say, unexpected discoveries at the very start of space research (Van Allen, S. N. Vernov, A. Ye. Chudakov). The discovery was made in 1958 during flights of the American Explorer-1 and Explorer-3, the third Soviet artifical Earth satellite, and also the Pioneer spacecraft. There was initially discussion of two radiation zones -- an inner and an outer, because in the first stage of the investigations measurement mainly of high-energy particles of around tens of millions of electron volts was carried out. After launch of the Explorer-12 artificial Earth satellite on which measurement of electrons with an energy $E_e \geqslant 40$ kev and low-energy protons with $E_p \geqslant 100$ kev was carried out, it was shown that the electrons do not form two separate radiation zones but only one. In addition it was shown that the intensity of the low-energy protons in the region of the "gap" between the inner and outer radiation zones is comparable with the intensity of the electrons. The inner capture boundary for these particles corresponds to the outer boundary of the geomagnetic field. Thus the entire zone of captured radiation is filled with low-energy electrons and protons of comparable intensity.

At present significant experimental information has accumulated based on the measurement of charged particles, their distribution, the intensity of the streams, the nature of motion in the geomagnetic field, and variations in the intensity. Establishment of the dependence of a captured radiation zone on local time was an important fact. This fact is presently acknowledged to be the most significant in the total physical picture of near-Earth outer space. Study of the captured radiation zone is of exceptional interest: a gigantic experiment on the acceleration and containment of charged particles /19
in a magnetic trap is placed before us by nature itself. An experiment of such scale is impossible to carry out as yet under laboratory conditions.

Measurement of the Low-Energy Plasma and the "Knee Effect"

The presence of intense particle streams with an energy higher than 200 eV in the region between $8.9 \leqslant R_E \leqslant 12.7$ was recorded by a device during measurements of a low-energy particles on the solar and dark sides of the Earth, which were carried out by Soviet scientists in 1959 on the first, second, and third space rockets (K. I. Gringauz). Streams of low-energy protons were measured on the second space rocket on the dark side, and it was first shown that in the altitude region from ~2,000 to ~15,000 km the ion concentration amounted to $\sim 10^3$ per cubic centimeter and $< 10^2$ per cm^3 at an altitude of 20,000 km.

Subsequent measurements by Explorer-10, Mars-1, and IMP-1 confirmed the effect of a sharp discontinuity in the plasma at an altitude of ~20,000 km.

In 1963 Carpenter (USA) discovered a sharp drop-off in the density of the plasma concentration at equatorial latitudes in the region $\sim 3 < R_E < 4$. He called this effect the "knee effect". The relation of the "knee effect" to the results of measurements on the second space rocket was noted by him. The collection of all measurements of the low-energy plasma inside the magnetosphere shows that at altitudes of ~20,000 km a sharp discontinuity occurs in the plasma, which is known as the plasmopause (the Gringauz-Carpenter effect).

The Magnetosphere's Boundary and the Dynamics of Charged Particles

The dynamics of charged particles during strong magnetic disturbances is rather complicated and until now has been studied little.

The first measurements at the magnetosphere's boundary during a magnetic storm were carried out on September 27, 1961 by the Explorer-10 satellite. Prior to the storm's commencement the satellite intersected the magnetosphere's boundary several times. The inner sections were associated not with the satellite's motion but with the disturbance of the geomagnetic field by solar streams and indicated that the magnetosphere's boundary is in continual motion about some quasi-steady equilibrium position. The sudden commencement of the storm was followed, according to the Explorer-10 data, by a rapid increase in the magnetic field strength in the boundary region and a compression of the /20 magnetosphere. The boundary effects associated with magnetic storms were also observed by the Explorer-12. It was discovered that during the first phase of the storm the magnetosphere's boundary approaches the Earth, i.e. the magnetosphere is compressed. During the storm's main phase the magnetosphere's boundary does not return to its previous position, but during the recovery phase the boundary increases and becomes larger than the undisturbed value. The amplitude of the oscillations of the magnetosphere's boundary reaches 2-3 Earth radii on the solar side during the storm. A sharp increase in the intensity of streams of charged particles in the boundary region is associated with the onset of a storm. This increase in intensity is associated with the arrival of a shock wave front from the Sun.

The Explorer-14 satellite was launched in 1962, and it carried instruments which recorded the variations in intensity of streams of charged particles on the magnetosphere's nighttime side. The intensity of streams of electrons with an energy $E > 40$ kev was subject to significant temporal variations in the evening and morning regions of the magnetosphere. These variations become especially large starting at distances of $R > 6R_E$ (R_E is the Earth's radius).

The Ring Current of Magnetic Storms

The discovery of the ring current of magnetic storms at distances of 3-5 R_E is an important geophysical discovery. This effect was first recorded during the flight of the first Soviet space rocket. It was then observed by the Explorer-6 and Explorer-10 satellites. During the flight of the Elektron-2 at the time of the magnetic disturbance of Februrary 12, 1964 a strong depression of the magnetic field on the morning high-latitude part of the trajectory was noted at a distance of $\sim 4\ R_E$. The depression effect was discovered several hours after the sudden onset, before the development of the main phase but during the development of the polar substorms (Dolginov, Yeroshenko, Zhuzkov). The development of the storm's main phase began in 5 hours at low and intermediate latitudes. The assumption was expressed (Dolginov et al.) that local deformations of the field are associated with the injection into the magnetosphere of some "active agent" which is also responsible for the development of the polar storms.

After the magnetic measurements by the Explorer-26 satellite and the direct measurements of the streams of electrons and protons with an energy from 200 eV to 50 kev in the 3-8 R_E region, it became possible to assume on sufficient grounds the actual existence of the ring currents of a magnetic storm, which is localized at distances of $3 < R_E < 5$ with a maximum density at /21
$\sim 3.5\ R_E$, and also to explain the magnetic field decreases observed during the storm's main phase. Cahill assumes that the storm's main phase develops because of the injection into the magnetosphere's depths of charged particles, most likely protons with an energy of ~ 100 kev.

Polar Aurorae

Numerous investigations have been carried out in the zone of the polar aurorae. Low-energy electrons are one of the principle agents causing polar aurorae. They were first recorded by the third Soviet artificial Earth satellite (V. I. Krasovskiy). Polar aurorae are a rapidly changing phenomenon; it is more suitable to conduct some investigations of them by rockets rather than by artificial Earth satellites.

Enormous information on polar aurorae is being accumulated as a result of ground-based measurements. The electrons which impinge on the upper atmosphere and produce the most beautiful and mobile shapes of polar aurorae have been investigated in detail. The spectrum of these electrons usually has a sharply-expressed maximum at an energy of ~ 5 kev, but more complicated spectra occur.

The low-energy protons, which are responsible for the formation of the weakly-glowing extended shapes of polar aurorae, have been poorly studied.

Their energy spectrum, estimated from ground-based observations, is similar to the energy spectrum of the protons in the solar plasma's flow zone around the Earth's magnetosphere. Evidently the protons of polar aurorae play an appreciable role in the energy balance and in supplying hydrogen to the upper atmosphere at high latitudes.

Still comparatively recently after the discovery of the Earth's radiation belt, experiments were conducted to explain the polar auroral phenomenon in terms of the energy supplied by particles in the Earth's radiation belt. Simple estimates showed that this energy would suffice for approximately 15 minutes for bright polar.aurorae. The polar auroral phenomenon presently remains at the center of attention of world geophysics.

Interrelationship of Geophysical Phenomena and Their Origin

The processes which occur in the Earth's radiation belt, the mechanisms of injecting particles inside the magnetosphere, their acceleration, shift to other drift envelopes, interaction with electromagnetic radiation, the connection of all these processes with a geomagnetic disturbance and polar aurorae are nevertheless studied little at the present time. Even the very detailed measurements of all the accompanying phenomena have been insufficient for these investigations. The creation of special satellite systems is necessary, since the measurements by an individual satellite do not permit separating the temporal variations from the spatial ones and investigating the processes which occur in various parts of the magnetosphere.

Nevertheless, it is possible to separate and partially explain a series of the phenomena. In the first place, the particle lifetimes on various magnetic envelopes are measured. This was done by various methods, in part, by measurements of the flux of particles dumped in the region of the South Atlantic anomaly, from measurements of the rate of drop-off in the intensity of artificially injected particles, and so forth.

The problem of the injection of particles inside the magnetosphere and their acceleration is a significantly more complicated one. The short lifetime and rapid variations in intensity and the region of capture show that the mechanism of the neutron albedo cannot maintain the observed intensity, with the exception, perhaps, of hard protons. Because the spectrum of the captured particles becomes harder upon transition to more interior magnetic envelopes, this fact is one of the arguments in favor of the betatron acceleration mechanism. Variations in the intensity of electrons at large distances from the Earth during geomagnetic storms can also, at least partially, be explained by adiabatic processes, although non-adiabatic losses and acceleration of the particles are observed.

One of the possible mechanisms of injecting particles into the Earth's magnetosphere is the bursting by solar wind particles through the neutral points at high latitudes. Recently some experimental data in favor of this idea have been obtained. Another possible mechanism, which has been worked out in great detail theoretically, is the diffusion of particles across the magnetosphere's boundary. It is possible to explain within the framework of this mechanism a series of regularities in the behavior of charged particles. However some calculations indicate the possibility of a larger rate of diffusion than has been assumed earlier. In this connection the appearance of low-energy protons on the outer magnetic boundaries which coincide in time with polar substorms is of interest. It is also not excluded that the penetration of particles into the polar auroral zone and the magnetosphere occurs from a reservoir of particles which exists on the nighttime side in the region of the geomagnetic tail and the neutral layer. Measurements over the polar auroral zones show that the capture of particles on geomagnetic lines of force is possible in the case of intense dumping of particles into /23
the atmosphere.

One can hope that further investigations of the magnetosphere with the help of systems of satellites on the outer envelopes near the neutral points and the neutral layer of the Earth's magnetic tail will permit solving many problems of the solar plasma's interaction with the geomagnetic field, understanding the nature of polar aurorae and magnetic storms, penetrating the concealed mechanism for accelerating particles inside the magnetosphere, and also understanding the nature of many processes in solar-terrestrial physics.

"My main work has always involved the development, realization, and the proving out under flight conditions of various rocket designs, starting from small rockets and continuing on to spacecraft." /24

S. P. Korolev

SPACECRAFT

The achievements of rocket and space technology in the USSR was used to solve the most urgent problems of contemporary science. Wide-scale scientific research and experimental design work has been conducted in this direction. It is difficult to overestimate the role which was played by the Soviet scientific research institutes and design offices, in whose operation the most prominent scientists of our country participated. Many important aspects of this work were coordinated by the USSR Academy of Sciences.

These efforts were completed with a triumph of Soviet science and technology by the launch on October 4, 1957 of the first artificial Earth satellite in the world. It was a sphere 58 cm in diameter with a weight of 83.6 kg. The satellite was equipped with a heat regulation system, a device for measuring the temperature, radio transmitters, and energy sources. Two antennas had a length of 2.4 m, and two other antennas, located in the perpendicular plane, had a length of 2.9 m.

The purpose for producing the first artificial Earth satellite was: a check of the scientific and engineering solutions employed in the design of the booster rocket and the satellite, investigation of the passage of radio waves through the ionosphere, proving out of the satellite's thermal system, and experimental determination of the density of the atmosphere's upper layers based on the satellite's decelleration. The satellite lasted 92 days and completed about 1,400 revolutions around the Earth.

The second artificial Earth satellite was launched in the Soviet Union on November 3, 1957. It had instrumentation to investigate the Sun's ultraviolet and X-ray radiation and measure cosmic rays. The dog Laika was on board the satellite, which was not separated from the booster rocket, for the purpose of studying the processes of vital activity under the conditions of space flight. Sensors attached to the animal's body recorded the pulse and /25 respiration rate, blood pressure, and other biological parameters. The prolonged influence of weightlessness on an animal's organism was studied for the first time.

On May 15, 1958 the placing into orbit of the third artificial Earth satellite was accomplished in the Soviet Union. The satellite was equipped with various instrumentation, with whose help it was possible to conduct investigations of the atmosphere's upper layers and near-Earth outer space. An experimental solar battery was used to operate the "beacon" radio transmitter. The weight of the third artificial satellite amounted to 1,327 kg. It completed more than 10,000 revolutions around the Earth and lasted until April 6, 1960.

"Kosmos" Artificial Earth Satellites

The systematic launches of artificial Earth satellites of the "Kosmos" series were begun in the Soviet Union for further investigations of near-Earth outer space in accordance with the program of the USSR Academy of Sciences explained on March 16, 1962. Included in the program were the study of the Earth's radiation environment and geomagnetic field, investigation of the Sun's ultraviolet and X-ray radiation, and the formation and distribution of cloud systems in the terrestrial atmosphere. Solving scientific problems, the "Kosmos" satellites helped to find answers to many engineering problems. What awaits a recoverable capsule upon entry into the Earth's atmosphere? What will be the effect of outer space on the elements of instrument design? How can one protect the crews of future spaceships from dangerous radiations, maintain their normal vital activity, and complete their landing in a specified region?

The wide range of scientific problems as well as the necessity for a large number of launches placed rigorous requirements on the originators of the "Kosmos" satellites. One of these requirements is the limiting unification of the designs and the accompanying systems, which makes it possible to organize the serial production of satellites and reduce their costs. This problem is very difficult. The point is that it is suitable to carry out part of the investigations on satellites with chemical sources of current while in other cases it is desirable to have a solar battery array which would supply the instrumentation for a long time.

The "Kosmos" satellites are able to conduct investigations "from above". Their instrumentation should be directed downward towards the Earth. The most characteristic examples in this respect are measurements of the energy of the Earth's outgoing radiation, the distribution of the radiation with altitude, and topography of the cloud cover. In this case the spacecraft should be oriented towards the Earth. In the case of study of the processes occurring on the Sun, one of the satellite's axes is constantly oriented toward the Sun /26 over a long time with the necessary accuracy (usually to several minutes of arc). When it is necessary to carry out a landing on the Earth of a container in which scientific instrumentation along with results of the measurements is contained, a braking engine assembly and parachute system is used.

Thus it is clear that the development of a single universal spacecraft is practically impossible, but the creation of several modifications of a unified satellite design is possible. This would permit solving this or that group of scientific research problems which are homogeneous or, at least similar in nature. Upon transition from one modification to another the maximum amount of design overlap is maintained, but the accompanying management systems and schemes do not depend on the specific problem to be solved by the satellite.

The development and creation of artificial Earth satellites of the "Kosmos" series are the most important stages in the study of the physics of outer space, as a result of which Soviet scientists have obtained a series of remarkable results. More than 300 satellites of the "Kosmos" series have been launched in the USSR up to the present time.

First Maneuvers in Space

On November 1, 1963 and April 12, 1964 the spacecraft "Polet-1" and "Polet-2" were placed into orbit around the Earth. They carried on board instrumentation and an engine system to carry out spatial maneuvers.

The subsequent development of space research placed before the designers the problems of creating special spacecraft for a more detailed study of physical processes occurring in space and obtaining simultaneous measurements at various points of outer space. Solution of this problem required the creation of an essentially new design for satellites launched simultaneously into separate orbits with the help of a single booster rocket. The "Elektron" space system belongs to this class of satellites. It consists of two scientific stations which are launched into different orbits, one with an apogee around 7,000 km and the other with an apogee of about 68,000 km.

The "Elektron" Space System /27

The first launch of an "Elektron" space system by a single rocket was conducted on January 30, 1964, and the second on July 11, 1964. The separation of the "Elektron-1" and "Elektron-3" stations was carried out during the active stage of the flight. The final stages of the booster rocket placed the "Elektron-2" and "Elektron-4" stations into greatly elongated elliptical orbit which permitted carrying out a wide combination of measurement.

The "Elektron" satellites made measurements of charged particles, the Earth's magnetic field, radio emission, X-ray radiation of the Sun, the atmosphere's ion contribution, micrometeors, and cosmic rays.

The study of cosmic rays is of definite interest from various points of view and above all for the investigation of those properties of elementary particles which appear only at sufficiently high energy.

Study of the nature of the high- and ultrahigh-energy primary cosmic ray particles, their composition and energy spectrum, the chemical composition of very heavy nuclei, the electron component, and high-energy γ-quanta permitted penetrating into the mechanism of their generation and interaction with the galactic and interplanetary medium.

Study of the composition and energy spectrum of the primary particles of high- and ultrahigh-energies is necessary to solve the problems of the mechanism of formation of the secondary particles of high energy which arise in the atmosphere as a result of the interaction of the primary particles with the nuclei of the air atoms.

In recent years the tendency has appeared to obtain the quantitative characteristics of this interaction and the creation of methods which provide a sufficiently unique interpretation of the experimental data.

In the Soviet Union this tendency became widely developed after the new method of measuring the energy of an individual particle was proposed by the Soviet physicist N. L. Grigorov. This method, based on the ionization calorimeter, makes it possible to combine different means of observing the interaction of particles with nuclei (Wilson cloud chambers, nuclear photoemulsions, and spark chambers).

The fluxes of high-energy cosmic ray particles are not very large. Their intensity falls off rapidly as the energy increases. To study such particles, instrumentation of large areas and measurements over a long time are required at a great altitude, since the primary cosmic rays are strongly absorbed in the atmosphere. Analysis of the possibilities of using cosmic rays to clarify many problems of the physics of high-energy particles has resulted in a conclusion as to the advisability of carrying out a series of experiments /28 beyond the atmosphere's limits on heavy Earth satellites, which permit raising an ionization calorimeter, and also additional instrumentation to investigate particles over a wide energy interval, to a great altitude and for a long time. The launch of the "Proton" series of scientific space stations was the first step in this direction.

The "Proton" Stations

On July 16, 1965 the "Proton-1" station, which had an enormously useful weight, was placed into a near-Earth orbit with the help of a new powerful booster rocket. Scientific instrumentation was located on board for the investigation of high- and ultrahigh-energy space particles.

Two other space stations, "Proton-2" and "Proton-3", were placed into orbit on November 2, 1965 and July 6, 1966. On November 16, 1968 "Proton-4", a new ultra-heavy scientific station whose scientific instrumentation had a weight of around 17 tons, was launched into orbit as an artificial Earth satellite.

Space stations of the "Proton" series were equipped with unique instrumentation to study solar cosmic rays, the chemical composition of the primary cosmic radiation in the 10^{10}-10^{14} eV energy region, the inelastic interaction of high- and ultrahigh-energy cosmic ray particles with matter, the energy spectrum of cosmic rays right up to energies of 10^{11}-10^{14} eV, the intensity and energy spectrum of γ-rays of galactic origin, the determination of the absolute intensity and energy spectrum of electrons of galactic origin, and a search for new fundamental particles with a fractional charge (quarks).

Flights to the Moon

Two schemes for flight to the Moon were worked out in the Soviet Union: a flight from the Earth to the Moon without a trajectory correction and a flight with an intermediate orbit as an artificial Earth satellite followed by a trajectory correction. Both methods required the creation of highly accurate systems for controlling the rocket's flight during its active phase and for the control of the spacecraft in flight and on-board system, including correction apparatus, orientation systems, and radio systems providing communications over many hundreds of thousands of kilometers, and in the case of /29 a flight to a planet, over hundreds of millions of kilometers.

Flights to the Moon and the planets are possible on specific astronomical dates. The plane of the Moon's orbit is inclined to the plane of the terrestrial equator by an angle of 18°. Because of this the Moon's declination, i.e., the angle made by the direction from the Earth's center to the Moon with the plane of the terrestrial equator, varies as the Moon moves along its orbit from +18° to -18°. In connection with this, it is energetically advantageous to carry out launches from the Soviet Union's territory when the Moon is situated near the point of its orbit with a minimum declination, i.e., -18°. The rocket moves with the least angle with respect to the terrestrial surface during the acceleration phase, and the velocity losses because of the Earth's attraction are minimal. This guarantees sending the largest load to the Moon. Upon a spacecraft's encounter with the Moon, it should be located above the horizon in order to provide an acceptable radio link with the spacecraft. Thus it is advantageous if at this time the Moon is located near the point of its upper culmination, i.e., its height above the horizon is greatest. Thus the most suitable parameters of the insertion trajectory and the starting time are selected for a specified point.

On January 2, 1959, the launch of the first space rocket in the Moon's direction carrying the automatic interplanetary station "Luna-1" was accomplished. The automatic station, which weighed 361.3 kg was separated during the flight procedure from the rocket's last stage. Special instrumentation to produce an artificial sodium comet was located on the last stage of the space rocket. The artificial comet was formed on January 3, 1959 at an altitude of about 100,000 kg from the Earth's surface and was observed by many astronomical observatories.

The "Luna-1" station passed into the immediate vicinity of the Moon at a distance of about 6,000 km from its surface. Subsequently the station entered an orbit as a solar satellite and became the first artificial planet of the solar system.

The launch of the second space rocket to the Moon was carried out on Spetember 12, 1959. The "Luna-2" automatic station was separated from its rocket and on September 14 at 00 hours 02 minutes 24 seconds, Moscow time[1], reached the Moon's surface. For the first time, a spacecraft, made by man's hands was propelled from one celestial body to another. The scientific instrumentation mounted on the "Luna-2" station permitted conducting a series of important investigations on the way to the Moon and in the immediate vicinity of its surface.

A third space rocket carried the "Luna-3" automatic interplanetary station /30 into an orbit around the Moon on October 4, 1959. On October 7 the lenses of the station's photographic instrumentation were directed by the orientation system at the side of the Moon invisible from the Earth, which was photographed at two scales, and the resultant images were transmitted to Earth by a television system.

[1]Henceforth, Moscow time will be used in this text.

As a result of this flight important information about the Moon's invisible side was obtained. The photographs obtained formed the basis for the first map of the Moon's reverse side.

Landing of Spacecraft on the Moon's Surface

The "Luna-9" automatic station, whose launch was conducted on January 31, 1966, successfully completed on February 3 the first soft landing on the Moon in the eastern part of the Ocean of Storms near the equator.

After landing, the "Luna-9" station began scanning the lunar landscape and transmitting its images to the Earth. A circular panorama of the lunar surface at various altitudes of the Sun was transmitted. People were first able to see in its immediate vicinity a small part of the Moon's surface, which permitted drawing some conclusions about the structure of the lunar surface. Dust was not discovered on the surface, and the soil appeared to be solid enought to support the pressure of the station. The transmitted photographs permitted distinguishing details of the lunar landscape with a resolution of several millimeters.

The launch of the "Luna-13" automatic station was carried out on December 21, 1966. It completed a soft landing on the Moon's surface also in the region of the Ocean of Storms. The station's flight lasted about 80 hours; a trajectory correction was carried out during the flight to ensure a landing at the specified region of the Moon. At a distance of 70 km from the Moon's surface the braking engine unit was turned on, and the "Luna-13" station, losing its velocity, set down softly on the surface. It also transmitted to the Earth a lunar panorama. The results obtained from the "Luna-9" station's data were confirmed. In addition the "Luna-13" station carried out direct measurements of the physical-mechanical properties of the lunar soil with the help of a series of instruments (soil meter, dynamograph, and radiation densimeter). Investigations of the radiation environment near the Moon's surface were also carried out.

After the flight of the "Luna-3" automatic station, with whose help the unique photographs were obtained of part of the Moon's reverse side invisible from the Earth, it was necessary to complete the photography of the lunar surface in order to compile a complete map of it. Special selection of the space probe's flight trajectory made it possible to solve this problem simultaneously with the solution of a series of other problems which are important for carrying out future interplanetary journeys. /31

The launch of a space rocket carrying the automatic station "Zond-3" was carried out on July 18, 1965. The station's video equipment was used to photograph the Moon's surface, some of which was that part of the Moon's side which is invisible from the Earth, which remained unfilmed during the photography carried out earlier with the help of "Luna-3". The photographs transmitted from the station were distinguished by high quality.

Thus after the flight of the "Zond-3" station, there remained almost no blank spots on the Moon's reverse side. Global photography of the lunar surface was practically completed.

Artificial Satellites of the Moon

The next step in the study of the Moon was the creation and launch of artificial satellites into a selenocentric orbit. They opened up a broad perspective in the study not only of cislunar space but also of the lunar surface's physical properties: chemical composition, magnetic and gravitational fields, and temperature.

On March 31, 1966 the "Luna-10" automatic station was launched in the Moon's direction. On April 3 it became the first artificial satellite of the Moon. The station's scientific instrumentation was intended to study the radiation environment in the Moon's vicinity, obtain the gamma spectra of the lunar surface and magnetic measurements, and study its thermal properties and the micrometeorite density near the Moon.

The second artificial satellite, the "Luna-11" automatic station, was placed into an orbit around the Moon on August 24, 1966, and on October 22, the third, "Luna-12", on which in addition to the scientific instrumentation was mounted video equipment to photograph individual sections of the Moon's surface from distances of from 100 to 340 km.

The program of lunar research of the "Luna-14" station, which was launched on April 7, 1968 and in three days became the next lunar satellite, provided for:

Refinement of the ratio of the masses of the Earth and the Moon, the Moon's gravitational field, and its shape by systematic extensive observations of changes in the lunar satellite's orbital parameters;

Investigation of the conditions of transmission and stability of radio /32 signals transmitted from the Earth to on-board the station and in the opposite direction at various positions of it relative to the lunar surface and also during the station's passages behind the Moon;

Conducting measurements of the streams of charged particles emitted from the Sun, and cosmic rays; and

Obtaining supplementary information for the construction of a theory of the Moon's motion.

On July 13, 1969 the flight to the Moon began for the automatic station "Luna-15", which became a new artificial lunar satellite. The "Luna-15" station differed from the preceding "Luna-9" and "Luna-13" stations in that its instrumentation provided for the possibility of landing in different regions of the lunar surface by changing its selenocentric orbit. During the station's flight around the Moon two maneuvers were carried out which resulted in the station shifting to a new orbit with a maximum distance from the lunar surface of 110 km and a minimum distance of 16 km. On July 21, 1969 at 18 hours 47 minutes, Moscow time, the braking engine unit was turned on and the station's velocity was slowed. Descent of the station to the Moon's surface began. Operation of the "Luna-15" station ceased at 18 hours 51 minutes, Moscow time.

Thus, during 1959-1969 great successes were achieved in the study of the Moon and data of great significance to subsequent flights to the Moon were obtained.

Circumlunar Flight with Return to the Earth

Creation of a series of spacecrafts capable of completing a circumlunar flight and accomplishing a landing in a specified region of the Earth's surface was required for the solution of the new problem, which arose in the study of the Moon, of delivery to the Earth of the results of investigations.

Spacecraft possess significant kinetic energy upon return to the Earth due to their enormous velocity. Upon entry into the atmosphere's dense layers a shock wave similar to the one which is produced during a projectile's motion is formed in front of the spacecraft. As a result, the atmosphere's equilibrium temperature between the shock wave and the spacecraft reaches on the order of 11,000°. A decrease in the spacecraft's velocity occurs because of aerodynamic resistance by which the spacecraft's kinetic energy is converted into the thermal energy of the surrounding gas, the main part of which is dissipated in space and only an insignificant part is absorbed by the spacecraft's surface.

The amount of thermal energy transmitted to the spacecraft during descent /33 in the atmosphere depends on the craft's shape, its ballistic coefficient, velocity and entry angle into the atmosphere, and on the duration of the heating. All this produces significant difficulties in the solution of the problems of the spacecraft's thermal protection. Therefore it can be successfully solved by means of selecting the appropriate aerodynamic shape for the craft, the optimum trajectory, and special thermally protective materials. The selection of the craft's shape is decided, as a rule, by a numerical method and then by a series of experimental checks, including actual space conditions, for example, during rocket launches.

Various methods are applied to carry off the heat from the spacecraft's surface, such as absorption by the casing material of all the incoming heat, radiation cooling of the craft's surface, the use of a thermally protective covering, and an exterior layer which melts and vaporizes as a result of the heating. A combination of all four methods is possible.

Upon the spacecraft's plunge into a planet's atmosphere, aerodynamic force begin to act on it, which are proportional to the atmospheric density the square of the velocity, and the aerodynamic coefficient. The force of aerodynamic resistance acts opposite to the direction of the velocity, decreasing the spacecraft's velocity. The craft's aerodynamic lift force acts simultaneously in the direction perpendicular to its motion, thereby producing an acceleration in this direction.

It is possible to obtain an aerodynamic lift force for spacecraft which have axisymmetrical and segmental-conical shapes without protruding parts by shifting the center of gravity relative to the axis of symmetry. As a result an angle of attack is produced which results in an asymmetric flow around the spacecraft and the creation of an aerodynamic lift force.

Spacecraft which possess an aerodynamic lift force considerably alleviates the solution of the problem of their return to the Earth upon entering the atmosphere with the escape velocity. A fundamental characteristic of a craft which possesses an aerodyanmic lift force is its lift-drag ratio, i.e., the ratio of the lift force to the drag. The higher the craft's lift-drag ratio, the lower is its drag, which in turn permits realizing a more moderately sloping reentry trajectory of the spacecraft, increasing the range of its flight, extending its maneuvering possibilities, and significantly lowering the spacecraft's thermodynamic overloads.

In order to accomplish guided descent of a spacecraft in a specific /34
region by using the lift-drag ratio, high accuracy is required for the craft to enter a definite entry corridor. In this case the craft is "captured" by the planet's atmosphere and undergoes permissible dynamic overloads. The spacecraft's guidance system should maintain not only the calculated atmospheric entry angle but also ensure the craft's entrance into the calculated entry point.

An essentially new design of spacecraft of the "Zond" series was developed to solve the problem of circumlunar flight by automatic craft and return to the Earth in the Soviet Union.

On September 15, 1968 the "Zond-5" automatic station was first placed into an intermediate orbit as an artificial Earth satellite with the help of a multi-stage booster rocket, and then launched to the Moon.

Having orbited the Moon, "Zond-5" station proceeded into a trajectory for the flight back to Earth. Upon approaching the Earth, a re-entry body in which the results of the scientific investigations were located, was separated from the station. On September 21, 1968 photography of the Earth was carried out from a distance of 90,000 km with the help of the photographic equipment of the "Zond-5". The special parachute system of the ejected body guaranteed the satisfactory descent of the "Zond-5" station into the Indian Ocean. The station's descent was accomplished along a ballistic trajectory. The flight of the "Zond-5" station along the Earth-Moon-Earth route lasted about 7 days.

On November 10, 1968 a new automatic station, "Zond-6" was launched towards the Moon. Checking out the systems for returning a body to a specific region of the Soviet Union by the use of guided descent upon entry into the Earth's atmosphere at the escape velocity was the main engineering task of the station's flight. In order to land the station at a specific region of the Soviet Union's territory after flight around the Moon, a re-entry body, entering the dense layers of the atmosphere, must traverse a distance of about 9,000 km. Such a considerable distance can be traversed only with a guided descent. The trajectory of the re-entry body consists of several segments: a first dive into the atmosphere, during which the re-entry body's velocity is slowed from 11 to 7.6 km/sec as a result of aerodynamic braking, the intervening extra-atmospheric flight, and a second dive into the atmosphere, which is concluded with the package's landing at the specified region.

On November 17, 1968 at 16 hours 58 minutes the re-entry body of the "Zond-6" station entered the dense layers of the atmosphere. With the help of an on-board computer the necessary flight program was selected for the first dive. After carrying out the flight program of the first dive the body exited the atmosphere's dense layers and began the intermediate unguided /35
flight preparatory operations were automatically carried out for the second dive of the body into the atmosphere: turning the body around an stabilizing it in the position necessary for guided descent. The guidance system automatically provided the necessary program for landing the re-entry body at the specified region. At an altitude of 7.5 km and a velocity of about 200 m/sec, the parachute system was deployed , and the body landed safely.

The flights of the "Zond-5", "Zond-6", and "Zond-7" stations permitted solving the following basic engineering problem: checking out the unmanned version of a manned spaceship for flight to the Moon; checking out the descent guidance system during the station's entry into the Earth's atmosphere at the escape velocity; and checking under flight conditions the aerodynamic shape and characteristics of the re-entry body. Besides solving engineering problems, an important group of scientific problems was solved by the stations of the "Zond" series, which carried out photography of the Moon and the Earth. The results of these investigations were delivered to the Earth. Thus, during 1959-1969 important successes were achieved in the study of the Moon and scientific data of great significance for solving the problem of interplanetary flight was obtained.

Flights to the Planets of the Solar System

The development of space rocket technology over the past decade has permitted extending significantly the possibilities for studying the planets of the solar system. On February 12, 1961 the first launch in history of an automatic interplanetary station, "Venera-1", to the planet Venus was accomplished in the Soviet Union. Subsequently a series of launches to Mars and Venus was carried out. During these flights, investigations of outer space was conducted, a check-out of the design of the spacecraft and its systems was carried out, and the problem of extra-long-range space radio communications and the guidance method was proved out by the extended flight of the automatic interplanetary stations.

The flights were performed during periods when the mutual position of the Earth and Mars (or Venus) was most suitable. These periods occur approximately every 19 months for flights to Venus and every 25 months for flights to the planet Mars. Just as in the case of the launches of automatic stations in the Moon's direction, the last stage of the rocket was in these cases first launched into an intermediate orbit as an artificial Earth satellite, from which /36
acceleration to escape velocity was realized in the prescribed direction.

The weight of the automatic interplanetary stations launched into distant interplanetary space amounted to about 1,000 kg.

The multi-month flights of the stations to the orbits of the planets Mars and Venus made it possible to check-out by means of the stations the automatic guidance system. It should be recalled that during the entire flight flight it is necessary to maintain a continuous orientation of the solar batteries towards the Sun, and this required the creation of an orientation system capable of operating during the many months of the flight in interplanetary space. Thus for the flight of the "Zond-2" automatic station plasma motors were used as the controls for the orientation system. Correction of the flight trajectory must be so accurate that the interplanetary automatic station would pass near the planet with errors not exceeding fractions of the planet's radius, and would in principle be directed along a trajectory for landing on the planet. This required the creation of a highly accurate orientation system using the Sun and the star Canopus as the reference point, which permitted giving the interplanetary automatic station the required angular position in space and thereby the necessary direction for the correcting impulse to change the station's flight trajectory.

The radio link with ground-base points was carried out both with the help of low-directional antennas and a highly directional parabolic antenna, which permitted transmitting a large amount of information to the Earth during the comparatively short period of transmission. In order that the parabolic antenna's axis be accurately directed at the Earth, appropriate devices of the orientation system, including an optical-electronic device capable of producing orientation towards the Earth from various distances, was used.

The communication subassembly, which includes equipment for trajectory measurements and also includes the subassembly's radio link and the radio link along which scientific information is transmitted to the Earth, is qualitatively new in comparison with similar subassemblies used during the launchings of artificial Earth satellites and the "Luna" series of automatic stations.

During the flights of the "Venera-1", "Mars-1", "Venera-2", "Venera-3" automatic interplanetary stations and also the "Zond" series of spacecraft, important scientific and engineering data were obtained. Included in this information were interesting data about the interplanetary magnetic field, cosmic rays, the interplanetary ionized plasma, long-wavelength radio emission, /37
scattered ultraviolet radiation and micrometeorite particles.

On June 12, 1967 the Soviet automatic station "Venera-4" was launched in the direction of Venus. On October 18, 1967 the station accomplished a smooth descent into the planet's atmosphere. An abundance of scientific data was obtained about the density and composition of Venus' atmosphere. For the first time a spacecraft with scientific instruments penetrated the mysterious depths of Venus' atmosphere and transmitted direct experimental data to the Earth.

On January 5, 1969 the automatic interplanetary station "Venera-5" was launched, and on January 10, the "Venera-6" station.

The main purpose for launching the "Venera-5" and "Venera-6" stations was the continuation of research of the planet Venus begun by the "Venera-4" station. The set of scientific and measuring instrumentation was significantly enlarged on the "Venera-5" and "Venera-6" interplanetary stations.

On May 16 and 17, 1969 the "Venera-5" and "Venera-6" stations completed a smooth descent into the planet's atmosphere.

In order to evaluate the engineering improvements of the guidance methods employed during the flight of the "Venera-4" station, we recall some data about this flight. During the flight there were 114 periods of radio contact, during which measurements of the station's distance, the radial component of the velocity, and angular coordinates were carried out. All this permitted conducting a continuous and very accurate watch over the actual flight trajectory.

The measurements showed that, in spite of the automatic station's holding well to the flight trajectory to Venus, a miss in the planet's neighborhood of

160,000 km from its center was obtained. In order to eliminate the miss a correction of the motion was carried out with the help of a rocket motor. This took place when the station was at a distance of 12 million km from the Earth. At the moment of the station's approach to Venus, it was located at a distance of 78 million km from the Earth. The encounter period of radio contact began when the "Venera-4" station was located at a distance of about 45,000 km from Venus. The station was reoriented so that the narrow-beam antenna was directed at the Earth. The station maintained this position until it entered the planet's atmosphere. After this the encounter period was ended and a descent body was separated from the interplanetary station. During the descent body's braking in the dense layers of Venus' atmosphere the G-force reached about 300 g. When the package's velocity decreased to approximately 300 m/sec, the parachute was deployed and the scientific instruments and radio transmitter were turned on. Descent into the depths of Venus' atmosphere and the transmission of scientific measurements lasted for 93 minutes. The place of the station's entry into the atmosphere was located (with an accuracy /38 of 500 km) on the nighttime side of Venus near its equator, at a distance of about 1,500 km from the terminator (the darkness boundary).

The flights of automatic stations to the planets of the solar systems permitted moving from an era of theoretical hypotheses about the nature of the planets of the solar system to their experimental investigation.

First Flight of Man into Space

In order to accomplish the first flight of a man into space, it was necessary to create and test in advance a powerful booster rocket and spaceship with complicated instrumentation to provide normal living conditions for the man during the flight. It was also necessary to solve the problem of returning the ship, upon its entering the atmosphere with orbiting velocity, create a system to provide a safe landing, and develop the means of reliable communications during flight and the ground-base control system during the ship's flight.

As a result of intensive effort, a new 3-stage booster rocket and the "Vostok" spaceunit were created in a short period of time. The booster rocket for the "Vostok" consists of six rocket units: four side units and one central unit constitute the first and second stages, where the liquid rocket engines are located, and the third stage with a -starting engine. The rocket's total length is 38 m, and its diameter at the base is 10 m.

Creation of the "Vostok" space rocket assembly was accomplished under the direction of Academician S. P. Korolev in close cooperation with the Chief engine designer, the chief control system designer, the chief launch equipment designer, the director of the ground-based measurement complex and other leading designers, engineers, and scientists. A cosmonaut training center was created in the USSR for the purpose of preparing cosmonauts for space flights. The most prominent scientists, instructors and engineers of our country took part in the operation of this center.

Five experimental spacecraft were launched in 1960-1961 to prepare the flight of a man into outer space and to test the spaceship.

The first of these entered its calculated orbit on May 15, 1960. All instrumentation and the radio command link for controlling the spacecraft functioned normally. The command to turn on the braking motor unit was sent from the Earth on the 64th revolution around the Earth. However because of a failure which appeared at that time in one of the orientation system devices, the direction of the braking momentum deviated from the computed direction, which prevented accomplishing the ship's re-entry to the Earth. /39

The second spaceship satellite was placed in orbit on August 19, 1960. The life-support systems for the cosmonaut were proved out on it. Two dogs named Belka and Strelka and other animals along with biological objects were placed onboard the spaceship. On the 18th revolution the spaceship safely landed at the specified region of the Soviet Union's territory. The animals were ejected and descended in a capsule suspended from a parachute. This was the first safe return of animals from space to the Earth.

The third spaceship satellite, which was placed into orbit on December 1, 1960, was to repeat the program of the second ship. Two dogs named Pchelka and Mushka were located in the cabin, After completion of the program, the spaceship was lost upon entering the dense atmosphere layers because of a deviation of the descent trajectory from that calculated. In addition to carrying out the tests of the ship's set of engineering systems and the biological results of flight, a large program of scientific investigations was conducted by the spaceship satellites. Main consideration was given to the study of the radiation environment in space at altitudes up to 350 km.

The fourth and fifth spaceship satellites, launched into orbit on March 9 and 25, 1961, respectively, each completed one revolution around the Earth. The flights of the fourth and fifth spaceship satellites performed the same programs which the first flight of a ship with a cosmonaut on board would follow. A mannequin of a cosmonaut, which completely simulated a person's weight, and also animals were located in the cabin of these ships: on the fourth -- a dog named Chernushka, and on the fifth -- Zvezdochka. Both ships safely completed the descent to the Earth at the specified region. This was the last general repetition before the flight of man into outer space.

On April 12, 1961 at 09 hours 07 minutes, the first pilot-cosmonaut, Yu. A. Gagarin, began his historic flight on the "Vostok-1" ship. This flight lasted 108 minutes, but these were 108 minutes which astounded the world with the courage and brilliant embodiment of man's breakthrough into outer space. A new era had begun -- the era of manned space flights.

The succeeding flights of Soviet cosmonauts were of great significance in clarifying the possibility of man's extended stay in outer space. The "Vostok-2" spaceship, which was piloted by pilot-cosmonaut G. S. Titov, went into orbit on August 6, 1961 and completed 17 revolutions around the Earth. The flight lasted 25 hours 18 minutes. G. S. Titov maintained his ability to work during the entire flight, however at isolated stages of the flight /40 some disturbances of the vestibular mechanism were noted by the cosmonaut.

The "Vostok-3" spaceship, which was piloted by pilot-cosmonaut A. G. Nikolayev, went into orbit on August 11, 1962. The flight lasted 94 hours 22 minutes. More than 64 revolutions around the Earth were completed.

One day later the "Vostok-4" ship was placed in orbit. It was piloted by pilot-cosmonaut P. R. Popovich. His flight lasted 70 hours 57 minutes. This was the first group flight of two ships in outer space.

One of the most important results of the group flight of the "Vostok-3" and "Vostok-4" ships was proof of the possibility of guiding a second ship into the immediate vicinity of the first, which should in the future facilitate maneuvers during the rendezvous and docking of spaceships. In addition, the possibility of man's normal vital activity under conditions of prolonged space flight was proven.

During the group flight the first pictures of cosmonauts from space were broadcast by the Soviet television network and transmitted to the countries of Europe through "Intertel".

The "Vostok-5" spacecraft, which was piloted by pilot-cosmonaut V. F. Bykovskiy, was placed in orbit on June 14, 1963. During the 119.4 hours of the flight the spacecraft completed 81 revolutions.

Two days later, on June 16, the "Vostok-6" spacecraft was placed into orbit. It was piloted by the first woman cosmonaut V. V. Tereshvkova. Her flight lasted 70.7 hours. More than 48 revolutions around the Earth were completed. The study of the effect of various factors of space flight on the human organism, including the male and female organisms, was continued in this joint flight. The cosmonauts endured the entry into orbit, the many--day flight, and the return to Earth well.

The next step for manned flight into space was the creation of the "Voshkod", a new multi-seat spacecraft. The spacecraft had equipment for a soft landing on the Earth's surface and an additional braking unit, which permitted performing flights in higher orbits than the "Vostok"-type spacecraft. In the "Vostok" the cosmonauts were able to perform the flight without space suits and without an ejection system. The spacecraft had, in addition to the previous orientation systems, a new system using ion detectors for the velocity vector's direction. The ship's weight amounted to 5,320 kg.

The "Voshkod-1" spacecraft was placed into orbit as an Earth satellite on /41
October 12, 1964 with an altitude at apogee of 408 km. A crew consisting of the spacecraft commander, pilot-cosmonaut V. N. Komarov, scientific associate K. P. Feoktistov, and physician-cosmonaut B. B. Yegorov was on board the ship. The flight lasted 24 hours 17 minutes. During the prolonged space flight an

extensive program for testing the 3-seat manned spacecraft was completed, the efficiency and interaction of the group of cosmonauts during the flight were investigated, and physical and engineering and other scientific investigations including medical and biological ones were carried out.

Man's Emergence Into Outer Space

On March 18, 1965 the "Voshkod-2" spacecraft was placed into orbit. It was piloted by a crew consisting of the ship commander, pilot-cosmonaut P. I. Belyayav and the second pilot, pilot-cosmonaut A. A. Leonov. On the flight's second revolution A. A. Leonov in a space suit with a self-contained life support system performed the first emergence from a spacecraft into outer space through a special hatch, successfully carried out the planned investigations and observations, and safely returned to the ship. Having completed about 17 revolutions around the Earth in 26 hours, the cosmonauts completed their landing on the Earth.

Man's emergence into open space proved the feasibility of man not only to perform flights but to actively work in outer space. The prospects of accomplishing assembly tasks in space, creating orbital stations with crew replacement, and creating spaceships for investigating the planets of the solar system were unfolded.

Extensive medical and biological experiments were undertaken in connection with subsequent training for the emergence of cosmonauts into open space. These experiments were intended to study the effect of a prolonged stay in outer space on a living organism. Such experiments were carried out, in part, on the "Kosmos-110" artificial Earth satellite. The satellite was placed into orbit on February 22, 1966. Two dogs named Veterok and Ugolek were on board. The satellite's orbit was selected so that its apogee reached 904 km, i.e., significantly higher than that of the "Vostok" and "Voshkod" spaceships. Thus the "Kosmos-110" satellite moved in a zone of increased radiation. The duration of the satellite's flight was 22 days, at the expiration of which the satellite completed a soft landing on the Earth together with the scientific instrumenta- /42
tion and the test animals. This interesting experiment gave valuable results in the field of space physiology.

Docking of Spaceship

To check the engineering ideas and design solutions for automatic docking two ships in Earth orbit, the "Kosmos-186" and "Kosmos-188" satellites ere launched on October 27 and 30, 1967. During the docking process of two spacecraft, one of them is "active". In other words it performed the search, detection, approach, and closing in. The second craft is "passive". It serves as a beacon for the"active" spacecraft. On October 30, 1967 on the 49th revolution of the "Kosmos-186" satellite's flight and on the first revolution of the "Kosmos-188" satellite's flight, automatic docking of two spacecraft was performed for the first time. The flight of the docked assembly lasted for 3.5 hours, after which, on command from the Earth, undocking of the satellites occurred. This was a most important step in the development of space technology.

The "Soyuz" Spacecraft

Simultaneously with the proving out of docking of spacecraft in space, new manned craft of the "Soyuz" series were created in the Soviet Union.

On September 23, 1967 the first experimental launch of the "Soyuz-1" craft was performed. It was piloted by pilot-cosmonaut V. M. Komarov, who earlier performed a flight as a member of the crew of the "Voshkod-1" craft. The purpose of the space flight in the "Soyuz-1" ship was a test of the new craft, checking out the systems and design elements under the conditions of space flight and conducting scientific engineering and medical and biological investigations. During the test flight by V. M. Komarov, the planned program was completely carried out. Upon completion of the flight of the "Soyuz-1" spaceship, the life of the outstanding pilot-cosmonaut V. M. Komarov was tragically cut short. The heroic deed performed by V. M. Komarov will go down forever in the heroic history of the conquest and investigation of space.

The "Soyuz" spacecraft characterize a new phase in the development of manned spacecraft. The "Soyuz" craft consists of an orbital compartment, which is the scientific laboratory and the cosmonaut's rest area, the pilot's cabin, which is the descent capsule in which the ship's crew is located during its entry into orbit and upon return to Earth, and an instrument equipment compartment in which the instrumentation and equipment of the ship's main systems and the engine unit are located. The ship's orbital compartment is connected to the descent capsule by means of an airtight lock. Panels of solar batteries with a useful area of about 14 m^2 are attached to the instrument equipment compartment. The liquid rocket engine unit has two motors (a main one and a back-up) with a thrust of around 400 kg each. This permits the craft to maneuver up to an altitude of 1,300 km. Upon descent from orbit after deceleration of the descent capsule in the atmosphere, a drogue parachute is deployed at an altitude of about 9 km, and then the main parachute. At an altitude of about 1 m from the Earth's surface the solid propellant braking engines are fired for a soft landing. This guarantees an immediate landing of the craft with a velocity not exceeding 2-3 m/sec. The large volume of the operational compartments (up to 9 m^3) creates the necessary conditions and comfort for the crew's operation. /43

The design improvements of the "Soyuz" craft, the reliable on-board systems, the economical engine installations, the scientific equipment, and the capabilities for maneuvering in outer space guarantee the fulfillment of an extensive program of space research. The "Soyuz" spacecraft should serve as the prototype for a "basic" ship for proving out and assembling orbital stations in space.

On October 25, 1968 the "Soyuz-2" spacecraft was injected into orbit around the Earth, and on the next day at 11 hours 34 minutes the "Soyuz-3" spacecraft was launched, piloted by pilot-cosmonaut G. T. Beregovoy. After the "Soyuz-3" craft entered orbit it separated from the transport rocket and conducted a radar search for the "Soyuz-2" ship. Having completed the radar search operation, the ships began to approach automatically to a mutual distance of about 200 meters. The subsequent rendezvous was carried out under the pilot-cosmonaut's control. Then the ships separated to a distance of 565 km. During repeated rendezvous G. T. Beregovoy photographed the "Soyuz-2" craft. Upon completion of the joint experiment the "Soyuz-2" craft was returned to Earth.

During the four-day flight of the "Soyuz-3", numerous maneuvers were carried out with the use of the automatic and manual control systems, the various systems of the spacecraft were tested, and scientific investigations were performed, in particular, observations of the stellar sky, Earth, and stars, photography of the cloud and snow-covers, the Earth's daytime and twilight horizon, observation of typhoons and cyclones, and medical and biological observations. During the flight, periodic television transmissions and reporting were carried out by cosmonaut G. T. Beregovoy.

On October 30, 1968, the "Soyuz-3" spacecraft successfully completed its flight. After braking, the descent capusle separated from the ship. It completed a controlled descent in the Earth's atmosphere using aerodynamic qualities and landed softly at the specified region. /44

The successful completion of the flight program of the "Soyuz-2" and "Soyuz-3" spaceships was an important step on the path to the creation of orbital scientific stations.

The First Orbital Stations

On January 14 and 15, the 1969 the "Soyuz-4" and "Soyuz-5" spaceships were placed into orbit as artificial Earth satellites. The "Soyuz-4" ship was piloted by pilot-cosmonaut V. A. Shatalov. The crew of the "Soyuz-5" spaceship consisted of: the ship commander, B. V. Volynov, the on-board engineer and Candidate of Engineering Sciences, A. S. Yeliseyev, and engineer-scientist Ye.V. Khrunov. During the joint flight of the ships, regular periods of space television were carried out, the manual orientation system was checked, observations of the stars and various objects on the Earth were made, and navigational measurements and medical and biological investigations were performed.

On the 32nd revolution, after the regular check of the "Soyuz-4" spaceship's orientation system, the engine unit was turned on and the ship moved into a new orbit. The engine unit was turned on with the help of a manual control system. On the 34th revolution of the "Soyuz-4" and the 18th revolution of the "Soyuz-5" their automatic rendezvous began. The distance between the ships as a result of the automatic rendezvous was reduced to

100 m. After this the commander of the "Soyuz-4" ship, V. A. Shatalov, switched to manual control. With the help of manual control V. A. Shatalov completed a series of maneuvers of the "Soyuz-4" ship and docked with the "Soyuz-5" ship. After docking, mutual mechanical capture of the ships, their rigid locking together, and connection of electrical circuits occurred.

On January 16, 1969 at 11 hours 20 minutes the first experimental space station was assembled and began to function in orbit as an artificial Earth satellite. It consisted of four compartments for the crew, which provided for the fulfillment of a wide range of experiments and investigations and also conditions suitable for working and resting. A telephone connection was established inside the station between its compartments. Both ships functioned normally during the rendezvous, docking, and hookup stages. The entire docking procedure was transmitted by television.

On the 35th revolution the cosmonauts, Ye.V. Khrunov and A. S. Yeliseyev /45 wearing space suits equipped with a new self-contained life support system of the regenerative type, went out through the lock of the "Soyuz-5" ship's orbital compartment into open outer space, where they stayed for about an hour carrying out scientific experiments and observations. After this the cosmonauts went over to the orbital compartment of the "Soyuz-4" spaceship, took off their space suits, and proceeded to carry out further tasks. During the transfer, a constant 2-way connection was maintained between the cosmonauts, and the exit of the cosmonauts into space and all the operations in outer space, including the assembling operation, were transmitted to Earth with the help of television cameras. This was the first time that a transfer of two cosmonauts from one ship to another had been carried out in the orbit of an artificial Earth satellite.

Performance of this experiment created the prerequisites for fulfilling such operations in space, as the replacement of the crews of permanent orbital stations or the rescue of spaceship crews under emergency conditions.

On January 16, 1969 at 15 hours 55 minutes the separation of the "Soyuz-4" and "Soyuz-5" spaceships occurred and their joint group flight began. After completion of the flight program the crew of the "Soyuz-4" spaceship, the cosmonauts V. A. Shatalov, A. S. Yeliseyev and Ye. V. Khrunov, began preparations for the ship's descent to the Earth. They packed all the experimental scientific instrumentation, motion picture, and photographic materials, and they checked the operation of the orientation systems. At the calculated point in the orbit the braking engine was turned on and the ship proceeded into the trajectory for descent to the Earth. After operation of the braking engine the orbital compartment was separated from the recoverable capsule. The descent in the Earth's atmosphere was completed by using the lift-drag ratio. When the capsule entered the calculated landing region, a parachute system was activated, and the soft-landing engines were turned on in the immediate vicinity of the Earth.

On January 17, 1969 at 9 hours 53 minutes the "Soyuz-4" spaceship safely landed 40 km northwest of the city of Karaganda. The "Soyuz-5", piloted by pilot-cosmonaut B. V. Volynov, continued its flight. The cosmonaut performed scientific observation of the Earth's cloud and snow covers and also geological and geographical objects of the terrestrial surface, checked the operation of the orientation system, and, with the help of the manual control system, reoriented the ship. Reorientation of the spaceship towards the Sun provides the ship with that position in space at which the Sun's rays are incident perpendicularly to the plane of the solar batteries, which provide the maximum yield of electrical energy for supplying the ship's systems and charging the storage batteries.

On the 36th revolution B. V. Volynov turned on the correcting engine unit /46 and performed a correction of the "Soyuz-5" spaceship's orbit. After completion of the flight program, the "Soyuz-5" spaceship successfully landed on January 18, 1969 at 11 hours 200 km southwest of Kustanay.

The "Soyuz" series of spaceships became genuine science ships. The flights of orbital spaceships permitted estimating in a new way the Earth's scale as a planet. While years were required by Magellan's caravelles to make the first circumnavigation of the Earth, a spaceship completes such a trip in an hour and a half. Such a short time essentially permits speaking about the simultaneity of the observation of changes occurring on the Earth and in near-Earth space. The new time scale permitted advancing a series of essentially new problems in geophysics and meteorology, i.e., in those sciences which basically are occupied with the study of sudden and rapid global processes.

For man in space the scale of surveying the Earth and its surface is enlarged on the one hand, and on the other hand prospects for deeper study of the processes occurring in the universe are opened up. All of this places the problem of conducting space experiments, such as those carried out by the cosmonauts on board a spaceship and in open space, in a new light.

One can cite as examples the measurement of quantities which change very rapidly in time, such as the level of space radiation during an outburst on the Sun, the intensity of streams of charged particles, the magnetic field strength during substantial disturbances, the motion of typhoons and cyclones, and the sudden changes in the melting boundary of snows and ice.

The presence on board of a cosmonaut-scientist or engineer simultaneously permits doing away with a series of automatic devices, i.e., substantially simplifying the design of the ships, and using the freed weight for the installation of other scientific instruments.

Qualitatively new opportunities in rocket technology have been uncovered with the creation of the first experimental orbital station. The opportunity is emerging for proving out such space operations as servicing and repairing space devices in orbit, group flight, rendezvous, docking, joining together, refueling and assembling interplanetary ships, and providing for their launching to the planets of the solar system.

Group Flight of Spaceships

On October 11, 1969 the flight of the "Soyuz-6" spaceship began in the Soviet Union. It was piloted by pilot-cosmonaut G. S. Shonin and the ship's on-board engineer Candidate of Engineering Sciences V. N. Kubasov.

During the two days of October 12 and 13 the "Soyuz-7" and "Soyuz-8" spaceships were launched. On board the "Soyuz-7" spaceship were pilot-cosmonaut A. V. Filitchenko, the ship's commander, V. N. Volkov, the on-board engineer, and V. V. Gorbatko, the engineer-scientist. The "Soyuz-8" spaceship was piloted by Hero of the Soviet Union, V. A. Shatalov and on-board engineer, Hero of the Soviet Union and Candidate of Engineering Sciences, A. S. Yeliseyev.

For the first time there was a group flight of 3 spaceships capable of performing various maneuvers in space, such as mutual rendezvous and docking, and carrying out observations of one another, including the use of optical signaling.

The program of the group flight included an extensive list of scientific, engineering, engineering design, and medical and biological tasks. The observations and photographing of geological and geographical objects was particularly important, as well as the testing with the help of a unique technological device of various methods of welding metals under the conditions of a hard vacuum and weightlessness.

The structural welding device was situated in the orbital compartment of the "Soyuz-6" spaceship, and the control panel for the welding process was located in the crew's cabin. On October 16, on the 77th revolution the ship's commander, G. S. Shonin, depressurized the orbital compartment. After a hard vacuum was established in the orbital compartment, the on-board engineer, V. N. Kubasov, turned on the welding equipment.

Several types of automatic welding were successively performed. In what way is the experiment performed a remarkable one? In the first place, the welding conditions themselves are unusual, namely, the hard vacuum, weightlessness, and the wide range of temperatures. In the second place, and this is important, it is necessary to decide to which type of welding known under terrestrial conditions to give preference in space and how a molten metal will behave in space. Performance of this unique experiment in space should answer any questions for the future development of the technology of welding under space conditions.

The observation of the terrestrial surface and photography of it was an important series of experiments performed during the group flights of the "Soyuz" spaceships. This new form of space information should serve as the basis for the solution of the national economic problem, namely, using spacecraft to study the Earth's natural resources and monitoring the conditions of crops, forests, and especially forest fires. Along with this the crews of spaceships have performed simultaneous astrophysical observations and experiments, and the polarization of the sunlight reflected by the atmosphere has been partially studied; measurements of the illumination produced by the Sun have been performed; the true brightness of stars has been determined, and an attempt was made to automatically orient a ship by the stars using manual control. /48

Checking the ground-based control operations was one of the main tasks of the group flight of "Soyuz" spaceships. The simultaneous control of the flights of three ships is a very complicated engineering problem.

After completing the flight program, the "Soyuz" spaceships made a landing at a specified region of the Soviet Union. The landing of all three spaceships proceeded along controlled descent trajectories using aerodynamic lift force.

Space Research in the USA

Intensive investigations of outer space developed over the last decade in many countries. The USA, France, Japan, and China became space powers. Along with the USA, investigations of outer space are being conducted in England, Italy, Canada, and also in some other countries within the framework of the European Space Research Organization.

American scientists and engineers were able after a series of failures to accomplish the first launching of an artificial Earth satellite, Explorer-1, on February 1, 1958.

The Explorer-1 satellite and the Vanguard-1, Explorer-3 and Explorer-4 which followed after it were intended to investigate cosmic rays and the physical parameters of the upper atmosphere. The first solar batteries used were on the Vanguard-1 satellite launched on March 17, 1958. The Explorer-1 satellite, the first in a series of American satellites, was a cylinder with a length of 2 m (together with the last stage of the transport rocket and the nose cone) and a diameter of 152 mm. The satellite's weight was 8.3 kg, and the weight of its scientific equipment was 4.5 kg. The satellite's casing was of steel, coated on the inside with glass-textolite. The satellite carried two transmitters, each weighing 220 grams.

The Explorer-4 satellite was launched on July 26, 1958 to study the aftereffects of a high-altitude atomic explosion in near-Earth outer space (Operation Argus). With the help of scientific equipment on the Explorer-3 and Explorer-4 satellites, the existence in near-Earth outer space of a zone of charged particles captured by the Earth's magnetic field was established. /49

Subsequent study of the zone of captured particles was conducted by the Explorer-6, Explorer-10, Explorer-7 and Explorer-12 satellites.

A significant number of heliophysical, astrophysical, and geophysical experiments in near-Earth outer space was conducted by the spacecraft: OGO (Orbiting Geophysical Observatory), OAO (Orbiting Astronomical Observatory), OSO (Orbiting Solar Observatory), and IMP (Interplanetary Monitoring Platform).

In 1958-1959 launchings of the Pioneer series of spacecraft were performed in the Moon's direction. The Pioneer-1 and Pioneer-3 spacecraft did not follow the calculated trajectory and in days, having reached altitudes of 114,000 and 102,000 km, respectively, returned to the Earth's atmosphere and ceased to exist. However in spite of so short a time of flight, important scientific results were obtained with their help. The Pioneer-4 spacecraft, launched on March 3, 1959, became the second artificial planet of the solar system.

The subsequent modification of the Pioneer series of crafts was intended to probe interplanetary space in a heliocentric orbit. On December 16, 1965 the first launch of the new series of craft, Pioneer-6, was performed. It was placed into a heliocentric orbit with the following parameters: perihelion at ~121.8 million km, aphelion at ~150 million km, and a period of revolution around the Sun of 311 days.

In order to obtain information about the relief of the lunar surface and to study its morphological peculiarities, launchings of the Ranger series of spacecraft to the Moon were carried out, starting in 1961. It was initially assumed that an instrument container with a seismograph would be delivered to the Moon's surface. However in the course of 3 years not one of the launchings concluded with the completion of the assigned program because of troubles.

in the control systems or in the on-board systems of the spacecraft itself.

On July 28, 1964 the Ranger-7 spacecraft was launched towards the Moon. On July 31, 1964 it reached the Moon's surface in the region of *Mare Cognitum*. Prior to impact the television system of the craft transmitted 4,316 very high resolution images of the lunar surfaces to the Earth.

The Ranger-8 spacecraft, which was launched to the Moon on February 17, 1965, impacted the Moon on February 20, 1965 in the region of *Mare Tranquillitatus;* it transmitted 7,000 pictures to the Earth. The last craft of the series, Ranger-9, was launched on March 21, 1965. During its approach to impact on the Moon 5,814 pictures were transmitted to the Earth. On March 24, 1965 the Ranger-9 spacecraft impacted the Moon's surface in the region of the crater Alphonsus. /50

The flight of the Ranger spacecraft did not involve a soft landing on the Moon's surface. This problem was solved with the help of the Surveyor series of craft.

Zoom and panorama television cameras were incorporated into the scientific instrumentation for the first launching. During succeeding launchings a retractable scoop, magnet, and alpha analyzer were used in various combinations.

The first launching of the Surveyor-1 spacecraft was performed on May 30, 1966. On June 2, 1966 it made a soft landing on the Moon's surface in the region of *Oceanus Procellarum.*

During 1966-1968 seven spacecraft of the Surveyor series were launched in all. Five of them made a soft landing. More than 80,000 pictures of the lunar surface were transmitted to the Earth during the photographic sessions, and scientific investigations were carried out on the Moon.

The Surveyor-6 spacecraft, which was launched on November 7, 1967, shifted its location on the Moon by about 2.5 m from its initial landing point on November 17 with the help of its rocket engines. After the shift the device continued normal functioning.

During the operation of the Surveyor-7 craft on the Moon, seven trenches were excavated by the retractable scoop and an investigation of the magnetic properties of lunar surface particles was conducted.

An investigation of cislunar outer space and global photography of the Moon was carried out with the help of artificial lunar satellites simultaneously with the study of the Moon by the automatic stations which performed a soft landing at various regions of the lunar surface.

This task was solved by the Lunar Orbiter automatic spacecraft. The main purpose for the launchings of Lunar Orbiter automatic spacecraft. The main of the lunar surface safe for the future landing of astronauts on the Moon.

The weight of the Lunar Orbiter spacecraft was 386 kg, including the weight of the photographic equipment, which was 68 kg. The photographic equipment included two cameras. The first camera provided photography with a resolution of 8 m for photography from the normal altitude of 46 km, and the second camera provided photography with a resolution of 1 m from the same altitude. Stereoscopic pairs of photographs could be obtained with the help of the first camera. The photography by both cameras was carried out simultaneously. The supply of photographic film on board was 80 m, which /51
provided for obtaining about 212 pictures with each camera.

The Lunar Orbiter was equipped with 20 meteor particle detectors with a total area of 0.28 m^2 and two dosimeters for studying the meteoric and radiation environment around the Moon. The main task of the dosimeters was the determination of the dose obtained by the photographic film.

During 1966-1967 five Lunar Orbiter craft were placed into selenocentric orbit. The first launch was performed on August 10, 1966. However, in view of the failure of one of the cameras, the planned program was not successfully accomplished in its entirety. About 211-212 planned pictures were obtained in each of the succeeding launches. On the basis of these pictures it was possible to draw the conclusion that there are places on the Moon suitable for the landing of a lunar capsule containing astronauts. In all 833 pairs of pictures were obtained from the five spacecraft. There is as yet no agreement among scientists in the interpretations in the pictures obtained by the Ranger and Lunar Orbiter spacecraft. According to a statement of the American astronomer Thomas Gold, these photographs represent a "magic mirror", in which each scientist sees a reflection of his own theory of the Moon's origin and its physical properties.

In 1962 American scientists undertook a series of attempts to perform the launching of spacecraft to the planets of the solar system. On August 27, 1962 the Mariner-2 spacecraft was launched toward Venus. On December 14, 1962 it completed a flyby of the planet at a minimum distance from Venus' surface during the flyby of 34,630 km. The craft's weight was 202.2 kg, including 18.44 kg of the scientific equipment.

On November 28, 1964 the Mariner-4 spacecraft was launched toward the planet Mars. On July 15, 1965 it performed a flyby past the planet at a distance of about 10,000 km. During the flyby the surface of Mars was photographed. Twenty-two photographs of the planet were transmitted to the Earth. Contact with the craft ceased on December 20, 1967. Based on the photographs obtained, the existence of large craters on Mars, to the craters on the Moon, was first established.

On July 14, 1967 the Mariner-5 spacecraft was launched toward Venus. It performed a flyby past Venus on October 19, 1967 at a minimum distance of about 4,000 km.

In February and March 1969 the Mariner-6 and Mariner-7 spacecrafts were launched. The purpose of these launches was the further study of Mars. The photographs made from on board the Mariner-6 and Mariner-7 interplanetary /52
stations finally resolved the enigma of the famous Martian "canals". The latter are the edges of gigantic craters. Mars is extremely similar to the Moon: its surface is mottled with craters, and its landscape is like a desert.

The flights of orbital spaceships constituted an important trend in the USA's program of space research. This program provided for two phases: flights of astronauts around the Earth and landing astronauts on the Moon. The first manned flights into space were performed by the American Mercury program.

The Mercury spaceship satellites were intended for the flights of one astronaut in a low geometric orbit. The preliminary shakedown of the ship was conducted during flights along a ballistic trajectory.

On May 5, 1961 an experimental model of the Mercury satellite, having received the designation Freedom-7 was launched along a ballistic trajectory and covered about 480 km. The American astronaut Shepard was in the ship's cabin. The maximum altitude of the flight was about 185 km. After 15 minutes of flight Shepard splashed down in the Atlantic Ocean.

The astronaut Grissom performed the next flight along a ballistic trajectory on July 21, 1961. The astronaut was picked up in the Atlantic Ocean. They did not succeed in saving the ship's cabin. In April-May 1961 experimental launchings of unmanned spaceship satellites were carried out.

On February 20, 1962 astronaut Glenn completed the first orbital flight in the Friendship-7 ship, having spent 4 hours 56 minutes in space. The flight's maximum altitude was 265 km, and its minimum altitude was ~159 km. The ship's weight without the abort system was about 1,300 kg. The ship was provided with an orientation system, a braking engine unit, and a splashdown system.

Subsequently three more launchings were performed in the Mercury program with the astronauts Carpenter (May 24, 1962), Shirra (October 3, 1962), and Cooper (May 15, 1963).

In 1964 experimental launchings of the Gemini series of ships and also the Saturn-1 rockets with a mock-up of the main unit of the Apollo spaceship were begun.

The first orbital flight of the 2-place Gemini-3 spaceship satellite with astronaut Grissom and Young was completed on March 23, 1965. The astronauts spent 4 hours 54 minutes in Earth orbit and reached a flight altitude ~240 km. Subsequent flights of the Gemini spaceships were performed at a high altitude. The flight time significantly increased.

The Apollo Space Program

/53

Work on the Apollo program was widely expanded in the USA simultaneously with the performance of the orbital flights in the Gemini program.

During 1962-1968 a new powerful rocket, the Saturn-5, along with the Apollo spaceship, was created and experimentally tested in the USA.

The Saturn-5 space rocket is a 3-stage rocket. The rocket's total length is 85.6 m. The first stage has a length of 42.1 m, the second stage with its adapter, 24.8 m, the third stage with its adapter, 17.8 m, and the instrumentation unit, 0.9 m. The rocket's diameter is 10 m. The first and second stages have 5 liquid engines, and the third stage 1. Liquid oxygen and kerosene are used as the oxidizer and fuel in the first stage, and liquid oxygen and hydrogen in the second and third stages. The Apollo spaceship is a 3-seat ship intended for flight to the Moon, landing the astronauts on the Moon, take-off from the Moon, and returning the astronauts to the Earth.

The Apollo spaceship consists of the command module, service module, and lunar module, including a landing stage and an ascent stage. The ship's total weight is about 36.5 tons.

On October 11, 1968 the Apollo-7 spaceship was placed into an Earth orbit with the help of the Saturn-1 B booster rocket. Astronauts Shirra, Eisele, and Cunningham were on board the ship.

The flight program of the Apollo-7 provided for carrying out all the necessary operations for a manned flight to the Moon and return to the Earth. During the flight the main engine was fired 7 times to perform various maneuvers in space. A check of the motor's operation in the mode for providing a transition from the geocentric orbit to the lunar flight trajectory and a check of the correcting maneuvers near the Moon were carried out. Performance of these operations indicated high reliability for the main engine's operation.

Checking the orientation system was an important part of the flight program, in part, turning the spaceship through 180° after the ship's separation from the last stage of the booster rocket and the ship's subsequent rendezvous with the last stage. Checking operation of the ship's on-board computer, navigational instruments, life support system, and electrical power system was also important.

The astronauts Shirra, Eisele, and Cunningham performed a series of experiments: photography of the Earth, in part, photography of hurricane Gladys, observation of stars in the daytime, observation of markings especially /54 lined up on the Earth for the purpose of determining the ability of the astronauts to use reference points on the Moon's surface, and visual observations beyond the terrestrial surface. The astronauts also conducted several television sessions.

On October 22, 1968 at 14 hours 12 minutes, the Apollo-7 ship splashed down several hundred kilometers southeast of Bermuda.

Flight of Man to the Moon

On December 21, 1968 the Apollo-8 spaceship with astronauts Frank Borman (ship commander), James Lovell, and William Anders was placed into an Earth orbit with the help of the Saturn-5 booster rocket. During the flight in geocentric orbits of the Apollo-8 spaceship, together with the third stage attached to it, a check of the functioning of all the on-board systems and preparation for turning on the last stage's engine were carried out. The ship along with the third stage was oriented so that its longitudinal axis was parallel to the terrestrial horizon. Two hours 50 minutes 31 seconds after the launch the last stage's engine was turned on once more and operated for 317 seconds. As a result the velocity increased from 7,800 to ~11,000 m/sec. The Apollo-8 spaceship flew onto a flight trajectory towards the Moon. After completion of the motor's operation and the transfer to the flight trajectory for the Moon the astronauts separated the last stage from the ship, and it moved to a distance of 15-20 m from it. The joint flight of the ship with the last stage was performed for more than 10 minutes, during which some operations necessary for guaranteeing the capability for docking the command module with the lunar module during subsequent flights were simulated. Subsequently the astronauts shunted the stage off to a safe distance and transferred it to a heliocentric orbit by turning on the auxiliary motors.

During the flight on the Earth-Moon route the Apollo-8 ship was oriented in space so that its longitudinal axis made an angle of 90 ± 20° with the solar direction. The ship was rotated around its longitudinal axis with a velocity of 0.1°/sec to maintain fixed temperature conditions. When the ship was at a distance of about 55,000 km from the Earth, the narrow-beam antenna, which guarantees a high quality of contact between the astronauts and the flight control center, was activated. The first trajectory correction of the Apollo-8 ship was carried out with the help of the main engine, when the ship /55 was at distance of about 96,000 km from the Earth. Several hours after performing the first correction the astronauts felt an indisposition (nausea, stomach sickness). After they took some motion sickness tablets the astronauts felt better.

During the flight to the Moon the astronauts conducted two television sessions. The second correction was performed at the Moon. The ship went behind the Moon, and when it was at a distance of 126 km from the lunar surface, the main engine was fired. The ship's velocity decreased to 1,600 m/sec, and it went into an elliptical selenocentric orbit with a periselene altitude of 113 km and an aposelene altitude of 312 km.

During the flight around the Moon the astronauts conducted a series of important experiments: photography of the Moon's surface and navigational measurement. A third television session was conducted. After completing two revolutions the astronauts performed a correction of the ship's selenocentric trajectory: for 9 seconds at periselene the main engine was turned on, after which the ship's trajectory around the Moon approached a circular orbit at an altitude of about 112 km.

The Apollo-8 spaceship completed 10 revolutions in its circular lunar orbit. A fourth television session, which lasted 25 minutes, was conducted from the circular orbit. On the 10th revolution a command was given to turn on the main engine, which operated for 203 seconds; the Apollo-8 ship's velocity was about 2,700 m/sec, and it took on a course directed toward the Earth. On the Moon-Earth route, when the ship was at a distance of about 310,000 km from the Earth, the ship's last correction was performed. During the return flight to the Earth two more television sessions were conducted, the last one from a distance of ~180,000 km.

On December 27, 1968 the Apollo-8 spaceship entered the dense layers of the Earth's atmosphere. Separation of the service module and the command module occurred. The command module soon splashed down. The historic flight of the astronauts Borman, Lovell, and Anders was safely completed after 147 hours. This was the first time that men from the Earth had flown around the Moon and returned to the Earth.

After the flight of the Apollo-8 spaceship it was necessary to conduct flight tests of the manned lunar module in a geocentric orbit with a simulation of all the conditions of landing astronauts on the Moon.

On March 3, 1969 the flight of the Apollo-9 spaceship with astronauts James McDivitt, David Scott, and Russell Schweickart was carried out. The ship was placed into a geocentric orbit.

The flight of the Apollo-9 spaceship lasted 10 days. The flight's /56
main task was a test of the ship's manned lunar module. The main operations in these tests were:

Rearrangement of the ship's compartment and its separation from the booster rocket's last stage;

Undocking of the lunar module and the command module;

Independent flight of the lunar module, separation of the module's ascent stage from the descent stage, and rendezvous and docking of the ascent stage with the command module;

Separation of the ascent stage without the astronauts and turning on the motor in this stage on command from the command module.

During the flight, on the fourth day after performing all the necessary operations, Schweickart performed extra-vehicular activity which lasted 47 minutes.

Having tested the space suit and the performance of the life support system, the astronaut returned to the lunar module, where McDivitt was located.

The astronauts conducted a television session from the lunar module and returned through the interior access tunnel to the command module to prepare for the main experiment, which was the independent flight of the lunar module.

On the flight's fifth day McDivitt and Schweickart, having put on their space suits, transferred to the lunar module. On the 59th revolution the lunar module was separated on Scott's command from the command module. The lunar module moved away from the command module to a distance of 15 m. After visual inspection of the lunar module, Scott turned on the auxiliary motors of the command module and shifted it to a different orbit, along which the command module moved at a distance of about 5.2 km from the lunar module. During this flight the distance to the command module and the radial velocity were determined with the help of an on-board radar altimeter mounted in the lunar module. The gyro-stabilized platform of the main guidance system was also adjusted and accurate data were entered into the emergency guidance system for the purpose of testing it prior to turning on the motor of the lunar module's landing stage.

On the 59th revolution the motor of the landing stage was turned on; its thrust was throttled within the limits of 10-40% of full thrust (~ 4.4 tons). As a result the lunar module moved into a more extended orbit with an apogee altitude of ~253 km. When the lunar module separated to a distance of ~ 89 km from the command module, a test of the radar altimeter, which guarantees a landing of the lunar module on the Moon's surface, was carried out.

Subsequently McDivitt and Schweickart successfully carried out all the following operations: turning on the landing stage's motor, turning on the main motor of the ascent stage, turning on the motors of the orientation systems, and braking and docking of the lunar module with the command module. /57
The docking of the lunar module with the command module was completed on March 7. After completion of all the operations with the lunar module and the transfer of the astronauts into the command module from the lunar module, the ascent stage was separated and went into an orbit with an apogee altitude of about 7,000 km. Thus the main experiment of the Apollo-9 spaceship's flight program was completed. The next 5 days of the flight were devoted to various

scientific and engineering experiments. With the help of optical instruments observation of ground-based reference points was carried out. The operation of the main engine was checked. Astronaut Scott made an observation of the planet Jupiter and four of its satellites with the aid of a sextant.

On the 152nd revolution the main engine was turned on for the 8th time to bring the ship out of orbit. The ship was turned by 45°. The service module was separated from the command module, which, passing into the dense layers of the Earth's atmosphere, splashed down in the Atlantic Ocean.

The tests of the manned lunar module of the Apollo spaceship in a geocentric orbit went successfully. However, in the opinion of the American authorities, it was necessary prior to the flight of astronauts to the Moon to carry out one more "dress rehearsal" of the spaceship in a selenocentric orbit with the performance of all the operations with the exception of the concluding one, namely, the landing of the lunar module with the astronauts on the Moon's surface.

On May 18, 1969 the flight of the Apollo-10 spaceship with astronauts Thomas Stafford, John Young, and Eugene Cernan began.

After carrying out all the planned operations in geocentric orbit the Apollo-10 ship moved onto a flight trajectory to the Moon. During the flight to the Moon only one trajectory correction, which was performed at a distance of about 200,000 km from the Earth, was required. After turning on the main engine, which operated for 356 seconds and imparted a velocity increment of 908.9 m/sec, the ship went into a selenocentric orbit with a periselene altitude of 109 km and an aposelene altitude of 313 km. 4.5 hours later the main engine was fired again and the ship shifted into an almost circular orbit. In the selenocentric orbit, astronauts Cernan and Stafford transferred from the command module to the lunar module to check the operation of its on-board systems. The check showed that all the systems were operating normally, after which preparation for performing the main experiment was begun. This experiment consisted of an independent flight of the lunar module and its rendezvous with the Moon at 15 km with simulation of all the necessary maneuvers.

On the 12th revolution undocking of the lunar module, where astronauts Cernan and Stafford were located, from the command module occurred. The undocking took place on the side of the Moon invisible from the Earth. When the lunar module and the command module appeared from behind the Moon and contact was reestablished with them, they were performing a group flight at a distance of 9-12 km from one another. The group flight lasted 25 minutes. Then various tests of the lunar module were begun in order that Young, located in the command module, could carry out photography of the module and check the correctness of its position in space. After this Young transferred the command module into a new orbit. /58

Turning on the motor of the lunar module's landing stage was done when the module was located above the invisible side of the Moon. The motor operated for 15 seconds at 10% of full thrust and then another 12.4 seconds at 40% of full thrust. The lunar module shifted into an elliptic orbit with a periselene altitude of 14.3 km ± 200 m and an aposelene altitude of 113.2 km. At periselene tests of the radar altimeter, which ensures the landing of the lunar module on the Moon's surface, were carried out. During the ships' flight in the selenocentric orbit the ship's orbit and then that of the lunar module were shifted somewhat under the influence of gravitational anomalies.

As a result the lunar module passed 6.4 km further south of the section of the lunar surface which was proposed for the module's future landing. It was determined that only 25-30% of the section's area is suitable for a safe landing, but if one performs a horizontal shift over the Moon's surface, then a landing is completely possible at the specified region. They were not successful in taking a photograph of the region because the camera was out of order.

After this the command module went through periselene, a firing of the landing stage's motor was again carried out. The module moved into a new orbit: 22 km at periselene and 350 km at aposelene. Then began the tests of the radar altimeter, which ensures an encounter in orbit of the lunar module and the command module. On the 22nd revolution, when the module passed through periselene at an altitude of 22 km, the ascent stage was separated from the landing stage on the second attempt. In order to move the ascent stage away from the landing stage, Stafford turned on the auxiliary engines of the ascent stage. At this moment an unexpected rotation of the ascent stage began. With the help of the manual orientation system Stafford, exhibiting courage and calmness was able to stabilize the ascent stage, after which the maneuvers for rendezvous of the ascent stage with the command module began. The ascent stage was oriented so that the motor's nozzle was directed forward along the direction of flight. Turning on the motor simulated the ascent from the Moon's /59 surface. The motor operated for 15 seconds, as a result of which the orbit's aposelene decreased to 86.4 km.

Subsequent maneuvers ensured rendezvous of the lunar module and the command module to within several meters. The operation of docking the lunar module and the command module was carried out by astronaut Young. In all, separate flight lasted about 8 hours. Astronauts Cernan and Stafford, having successfully completed the program of the main experiment with the lunar module, reentered the command module. The ascent stage was separated and the command module moved to a safe distance. After this, astronauts Cernan, Stafford, and Young, located in the command module, continued their flight around the Moon for about 24 hours. During this time an entire series of scientific and engineering experiments was carried out. On the 32nd revolution the command module's main engine was fired. It operated for 164 seconds, and the ship transferred from its selenocentric orbit to a flight trajectory for the Earth. On the Moon-Earth leg of the flight only one correction was carried out. During the days prior to spash down the astronauts shaved.

On May 26, 1969 the Apollo-10 spaceship splashed down safely. The flight of the Apollo-10 spaceship completed the entire experimental program of preliminary tests for the successful performance of the last stage of the lunar odyssey -- the landing of astronauts on the Moon's surface. During the Apollo-10 ship's flight, color space television sessions were carried out for the first time.

Landing of Man on the Moon's Surface

The preparation for launching the Apollo-11 spaceship began when the Apollo-10 ship flew toward the Moon. On May 21, 1969 the gigantic

Saturn-5 booster rocket along with the Apollo-11 spaceship were transported from the Vertical Assembly Building to the launch complex of the spaceport at Cape Kennedy. The spaceship's command module was to perform a landing on the Moon's surface to complete the American program of manned lunar flights. On July 15, 1969 preparation for the launch of the Apollo-11 spaceship was concluded.

The three American astronauts Neil Armstrong, Michael Collins, Edwin Aldrin took their work stations in the spaceship's command module in order to perform their historical Earth-Moon voyage. At various times in 1966 these three astronauts had already completed flights into space. They went through /60
a complicated phase of ground-based training.

On July 26, 1969 at 16 hours 32 minutes the launch of the Apollo-11 spaceship was begun on command from a computer. After flight in a near-Earth intermediate orbit the spaceship transferred with the help of the third stage engine into a flight trajectory for the Moon. The trajectory was similar to the computed one and only one correction was required in all. On the Earth-Moon leg of the trip the operations proved out earlier were performed: rearrangement of the compartments and separation of the last stage of the booster rocket.

In the evening on July 19, 1969 the Apollo-11 spaceship transferred into a selenocentric orbit by a special maneuver. The spaceship was in an orbit of the Moon for about a day. A series of television sessions, navigational measurements and corrections of the ship's orbit were carried out at this time, as a result of which it transferred to a circular selenocentric orbit. After completing these operations the astronauts Armstrong and Aldrin transferred to the lunar module in order once more to check its readiness for landing on the Moon.

On July 20, 1969, Eagle, the lunar module with astronauts Armstrong and Aldrin, separated from Columbia, the command module, which remaind in lunar orbit together with astronaut Collins. The fuel supply permitted Eagle to perform a horizontal flight over the Moon's surface for 2 minutes. Astronaut Armstrong had at his disposal mere seconds to estimate the situation, select a level area, and land the lunar module. Neil Armstrong handled the situation splendidly. On July 20, 1969 at 23 hours 18 minutes Eagle landed on the Moon's surface in the region of *Mare Tranquillitatus*. The astronauts rested after the lunar landing.

On July 21, 1969 at 5 hours 56 minutes, Neil Armstrong became the first man in history to set foot upon the Moon. Twenty minutes later Edwin Aldrin joined him. The exit of the astronauts from the lunar module and their first steps on the Moon were broadcast to the Earth by television. The astronauts set up a series of scientific instruments on the Moon, collected samples of the lunar soil, and left an inscription at the landing site: "Here men from the planet Earth set foot upon the Moon, July 1969, A.D. We came in peace for all mankind."

At 8 hours 15 minutes Armstrong and Aldrin returned to the lunar module. The astronauts rested for approximately 7 hours, then began preparation for the launch of the ascent stage from the Moon's surface. This preparation lasted for about 3 hours.

On July 21, 1969 at 20 hours 54 minutes the lunar module's ascent stage /61
was launched from the Moon's surface. The module's landing stage remained on the Moon. The rendezvous process of Columbia and Eagle lasted 3 1/2 hours.

After completion of the rendezvous the astronauts transferred to the command module, and the used ascent stage was discarded and remained in selenocentric orbit. Having fired the command module's main engine, which operated for 149 seconds, the astronauts began their flight back to the Earth. A trajectory correction, which guaranteed the ship's entry at a specific landing site, was carried out at a distance of about 300,000 km from the Earth. During the flight back to the Earth the final color television session occurred. In view of adverse meteorological conditions it was necessary to change the landing site. As a result of this the Apollo-11 spaceship's descent in the Earth's atmosphere occurred using the lift-drag ratio. After separation of the service module and the command module, the latter entered the Earth's atmosphere at an altitude of 120 km.

On July 24, 1969 the command module splashed down at a point with the coordinates 13°30' N.latitude and 169°15' W.longitude. Pressurized suits were passed through the hatch to the astronauts which they wore when they left the command module. Then the pressurized suits were treated with the disinfectant agent, Betadyne (an inorganic iodine compound). Sixty-three minutes after the splashdown, Armstrong, Aldrin, and Collins were delivered aboard an aircraft carrier and they went directly from the helicopter to a quarantine van. On July 27 the aircraft carrier Hornet arrived at the port of Pearl Harbor, and the van with the astronauts was delivered the same day to a special laboratory in Houston. Upon conclusion of a 21-day quarantine stay at Houston, the astronauts were ceremoniously greeted on August 13, 1969 in New York, Chicago, and Los Angeles.

Thus the first journey in history to the Moon was completed.

* * *

Recently the entire world found out about a new magnificent success of Soviet cosmonautics. On April 25, 1970 eight "(!)" artificial Earth satellites ("Kosmos-336" -- "Kosmos-343") were launched with the aid of a single booster rocket.

Scientific equipment was mounted on these satellites which is intended to continue the investigations of outer space in accordance with the program explained earlier.

Besides the scientific equipment, the satellites contained radio systems for the accurate measurement for the orbital elements and radiotelemetry systems to transmit to Earth data on the operation of the instruments and scientific equipment.

Soviet scientists and designers continued to carry out the enormous /62 tasks directed toward utilization of outer space and the investigation of the planets of the solar system nearest to us.

The Sixties of our century became a genuine triumph of space rocket technology, and the effort of the space conquerors has become a memorial of human effort in general. We are approaching a new point in our century, when the engineering capabilities are harnessed to produce the greatest scientific discoveries about the universe.

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